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November 2008

Shark Deterrent and Incidental Capture Workshop
April 10–11, 2008

Compiled and Edited by

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Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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EXECUTIVE SUMMARY

Elasmobranch (shark and ray) bycatch is a significant cause of concern for U.S. and international fisheries (Barker and Schluessel, 2004; Gilman et al., 2007; Mandelman et al., 2008). NOAA Fisheries has recognized shark bycatch as a management-priority fisheries challenge and has indicated that "Management entities should invest in elasmobranch research, fishery monitoring, reduction of bycatch and bycatch mortality, minimization of waste, and enforcement" (NMFS, 2001). In response, the NOAA Pacific Islands Fisheries Science Center (PIFSC) Fishery Biology and Stock Assessment Division (FBSAD) has to identify and test the effectiveness of strategies and techniques for reducing elasmobranch bycatch in fisheries, including longline fisheries targeting tunas and swordfish. Based on the Magnuson-Stevens Act National Standard 9, the national standard regulating bycatch in fisheries (50 *CFR* 600.350), the first priority for reducing bycatch should be to avoid catching bycatch species where possible, and when bycatch cannot be avoided, to minimize mortality of such bycatch.

In the Pacific Islands Region and in many other regions, elasmobranch bycatch on pelagic longline gear is a significant bycatch issue (Gilman et al., 2007; Mandelman et al., 2008). Elasmobranch bycatch is also very high in trawl (Zeeberg et al., 2006; Shepherd and Myers, 2005; Stobutzki et al., 2002; and Cedrola et al., 2005) and gillnet (Perez and Wahrlich, 2005; White et al., 2006) fisheries worldwide. The incidental capture of sharks is estimated at more than 300,000 metric tons annually (Bonfil, 1995), and in some non-shark pelagic longline fisheries, sharks comprise a large proportion of the total catch. For instance, sharks comprise > 25% of the total catch in the Australia longline tuna and billfish fishery and Fiji longline tuna fishery (Gilman et al., 2007). Prior to a prohibition on the use of squid for bait, sharks made up 50% of the catch of the Hawaii-based longline swordfish fishery, but sharks currently make up 32% of the catch (Gilman et al., 2007). The proportion of oceanic pelagic elasmobranchs classified as "threatened" by the International Union for Conservation of Nature (52%) is more than double that of all assessed chondrichthyans (21%; Dulvy et al., 2008). Since sharks and other elasmobranchs are among the top predators in ocean ecosystems, the continued depletion of their populations through fishing could result in detrimental cascading effects for high seas biodiversity (Stevens et al., 2000; Myers et al., 2007).

Understanding the sensory and behavioral ecology of elasmobranchs is an important component for developing strategies aimed at reducing shark and ray incidental capture in longline and other fisheries. Feeding behavior of elasmobranchs involves processing by various sensory systems, including their visual, chemosensory, auditory, lateral line (provides the ability to sense water movement and pressure), and electrosensory components or units (provides the ability to sense extremely weak electrical fields). Experiments examining the use of sensory cues that influence feeding behavior are critical in the design of effective strategies for reducing unwanted bycatch of sharks, skates, and rays. The primary objective of the research projects described herein is to develop techniques and/or commercially viable devices that eliminate or substantially reduce longline interactions with sharks while maintaining target species catch rates that are economically viable.

This report summarizes findings reported by scientists at a Shark Deterrent and Incidental Capture Workshop cosponsored by the Consortium for Wildlife Bycatch Reduction, the New England Aquarium, and NOAA PIFSC. The meeting was held at the New England Aquarium in Boston, Massachusetts during April 10–11, 2008. Participants of this workshop included NOAA fisheries biologists, researchers from U.S. and foreign universities, and consultants from private companies. A list of participants and their affiliations is included at the end of this report.

We would like to thank Tim Werner, John Mandelman, Amanda Thompson, and the staff of the Consortium for Wildlife Bycatch Reduction and the New England Aquarium for hosting the workshop. Additionally, we thank Marcia Oshiro of the Joint Institute for Marine and Atmospheric Research at the University of Hawaii (JIMAR) and Laila Apostol of NOAA PIFSC for coordinating travel logistics. We also thank Lee Benaka for allowing funds from the NOAA Bycatch Reduction Engineering Program to be used for this workshop. Other funding sources include PIFSC and the University of Hawaii/JIMAR visiting scientist fund.

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CONTENTS

An Overview of Shark Bycatch in Pelagic Fisheries: Conservation and Ecology of Pelagic Sharks

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ELASMOBRANCH LANDINGS HISTORY

Global landings of elasmobranch fishes (sharks, rays, chimaeras) increased steadily through the last half of the 20th century but have leveled off in recent years (Fig. 1; data from FAO). Landings in the Indian, Atlantic, and Pacific Oceans currently contribute nearly equally to the total. However, the majority of the global increase in landings comes from the western Indian Ocean and the western central Pacific Ocean; the highest landings currently occur in India and Indonesia. Some have suggested that reported landings represent as little as 50% of total fishing mortality on elasmobranchs (Bonfil, 2002), and Clarke et al. (2006) estimated that global annual trade in sharks was 1.21–2.29 million metric tons.

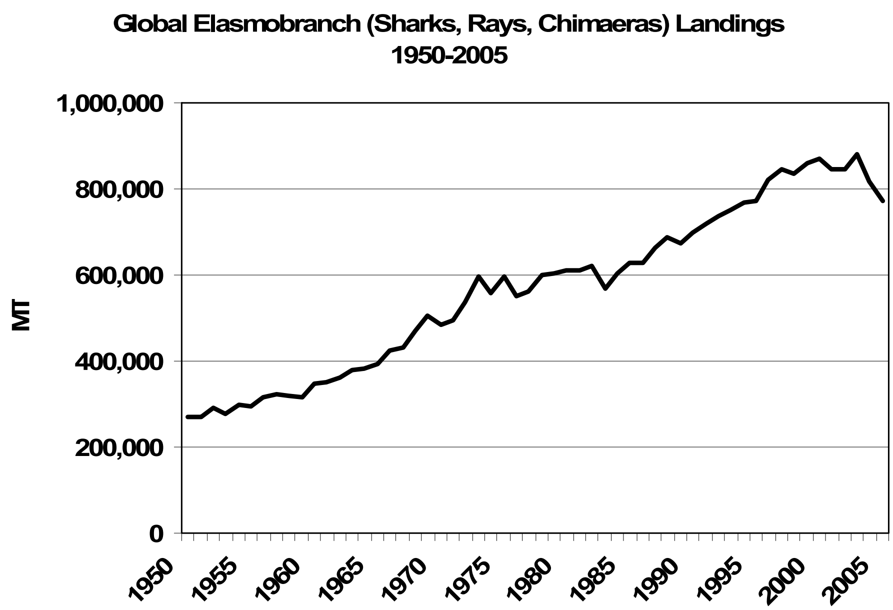

Figure 1.—Global landings of elasmobranchs through the last half of the 20th century in metric tons (MT) (FAO, 2005).

FISHERIES

Three primary fishing gears that are used in high-seas fisheries commonly capture sharks as target or bycatch species: purse seines, gill nets, and pelagic longlines. Purse seines are the dominant gear type for tropical tuna fisheries. In the western and central Pacific Ocean, they accounted for 73% of the tuna catch in 2007. In the western and central Pacific, purse seiners target unassociated (free-swimming) schools or fish associated with floating objects, such as logs or fish aggregating devices (FADs). Relatively low bycatch is generated by these fisheries. For example, according to observer data taken from 1994 to 1997 (Williams, 2002) for the western tropical Pacific, less than 2 kg of shark bycatch were caught in purse seines for every 1000 kg of targeted catch (tunas). In the eastern Pacific, purse seine fisheries traditionally targeted unassociated tuna schools or schools associated with dolphins. Various influences, including the Dolphin Safe Tuna campaign, led to a major shift in purse seine fisheries in recent years to primarily target tunas associated with floating objects, especially FADs. In the eastern Pacific, overall bycatch in purse seines set on floating objects may be 75 times that of sets on dolphin-associated tuna schools (Hall, 1998). Hall (1998) estimated that shark bycatch in floating object sets was 13 times higher than sets made on dolphin-associated tuna schools.

Sharks are often the dominant bycatch in pelagic longline fisheries. In the western tropical Pacific, the target catch (tunas) to shark bycatch ratio from 1994 to 1997 was only around 2.2 (10 tunas and 4.5 sharks per 1000 hooks; Williams, 2002). Gilman et al. (2007, 2008) compared shark catch rates for 12 pelagic longline fisheries from around the world. Catch rates ranged from 0 to 24 sharks per thousand hooks set. Shark bycatch rates were lowest in high seas fisheries targeting tunas (e.g., Japan distant water tuna fishery, Fiji tuna fishery, Hawaii tuna fishery) and highest in fisheries that fish shallower (e.g., Chile artisanal mahimahi fishery, Hawaii swordfish fishery, Chile swordfish fishery). Blue sharks were the dominant shark species in all 12 fisheries (47–92% of total shark catch). Silky sharks and oceanic whitetip sharks are the next most common elasmobranch species caught in pelagic longline fisheries. Retention rates of sharks vary, although these three species of sharks are discarded alive in most fisheries. Retention of marketable species, such as shortfin mako sharks and the three species of thresher sharks, is typically higher. Some fisheries retain all sharks caught as bycatch. For example, swordfish fisheries off the coast of Uruguay that have extremely high shark bycatch rates (~ 40–85 sharks per 1000 hooks) typically retain and market more than 95% of the blue sharks captured (Marin et al., 1998)

MITIGATION

Alteration of fishing methods, including changes in fishing depth, leader material, bait, and hook type can greatly decrease shark bycatch and mortality on pelagic longlines. As mentioned above, shark catch rates are greatest on shallow sets. For example, Williams (2002) reported that catch rates of blue sharks and silky sharks were 2.8 and 6.4 times higher on shallow set longlines than on deeper set longlines. Similarly, Bartram and Kaneko (2004) reported that shark bycatch was less than 1% of the target catch for deep-set longlines but between 3% and 15% of target catch in shallow-set longline fisheries. Requiring hook depths greater than 100 m would greatly decrease shark bycatch in longline fisheries for most species. Fishers who wish to avoid the capture of sharks have long recognized that use of monofilament leaders instead of steel leaders decreases shark catch rates (Beverly et al., 2003). Some pelagic fisheries no longer allow the use of steel leaders for this reason (Gilman et al., 2007, 2008). Bait type can also influence shark bycatch rates. Watson et al. (2005) found that blue shark catch rates were significantly lower when using mackerel as bait instead of squid. Data on the influence of hook type on shark catch rates are equivocal. However, rates of gut-hooked animals are much lower using circle hooks than J-hooks, suggesting post-release mortality of captured sharks may be reduced by the use of circle hooks (Cooke, 2005).

LIFE HISTORIES

The sharks most commonly caught in high seas fisheries come from three families: Carcharhinidae, Lamnidae, Alopiidae. Compared to the teleosts that are usually the target species of these fisheries, all shark species captured are reproductively limited because they mature late, gestate for long periods, and produce few offspring via advanced forms of viviparity. Population doubling times for pelagic sharks, in the absence of fishing mortality, are typically between 10 and 15 years (Smith et al., 1998). Some large coastal sharks that are commonly captured in nearshore fisheries have population doubling times of more than 20 years. Pelagic sharks are likely more resilient to fishing mortality than many large coastal species and may rebound more quickly if mortality declines. The table below is taken from Smith et al. (1998). It is important to recognize that these life history parameters are estimates, and there are large variations in estimates of these parameters within species, between populations, and even within populations. Estimates of maximum age are particularly problematic and are not reliable information.

Table 1.—Life history parameters and population doubling times for selected shark species (Table is from Smith et al., 1998). Most common pelagic species in high seas fisheries are in red boxes.

α = Female Maturity (years)

w = Max. ♀ Age (years)

b = ♀ Fecundity (number of female pups per litter)

M = Nat. Mortality (rate per year)

r_{2M}= Productivity (rate per year)

T_D= Doubling Time (years)

Smith et al. (1998)

	α	*w*	*b*	*M*	r_{2M}	T_D
Gray smoothhound	2	12	1.6	0.368	**0.136**	5.1
Br. smoothhound	2	15	1.9	0.295	**0.127**	5.4
Bonnethead	3	12	4.5	0.368	**0.105**	6.6
Sharpnose	4	10	2.5	0.440	**0.084**	8.2
Common thresher	5	19	2.0	0.234	**0.069**	10.0
Oceanic whitetip	5	22	3.0	0.203	**0.067**	10.3
Blue	6	20	11.6	0.223	**0.061**	11.4
Blacktip	7	18	2.6	0.247	**0.054**	12.8
Gray reef	7	18	2.5	0.247	**0.054**	12.8
Sand tiger	6	35	1.0	0.129	**0.052**	13.3
Mako	7	28	4.0	0.160	**0.051**	13.6
Whitetip reef	8	16	1.1	0.277	**0.048**	14.6
Galapagos	8	24	4.0	0.186	**0.048**	14.5
Silky	9	25	2.6	0.179	**0.043**	16.0
Tiger	9	28	17.2	0.160	**0.043**	16.3
White	9	36	3.5	0.125	**0.040**	17.2
Angel	10	35	3.0	0.129	**0.038**	18.2
Lemon	12	25	4.1	0.179	**0.034**	20.5
Spiny dogfish[A]	10	50	3.0	0.091	**0.034**	20.3
School/ Soupfin	12	40	14.0	0.113	**0.033**	21.3
Leopard	13	30	6.0	0.150	**0.032**	21.9
Sandbar	15	30	3.9	0.150	**0.028**	25.1
Scalloped hammerhead	15	35	10.8	0.129	**0.028**	25.1
Bull	15	27	1.8	0.166	**0.027**	25.7
Sevengill	16	32	44.1	0.140	**0.026**	26.6
Dusky	21	40	3.2	0.113	**0.020**	29.9
Spiny dogfish[B]	25	70	3.6	0.065	**0.017**	41.5

CONSERVATION

Shark species captured in pelagic fisheries are wide-ranging and most are cosmopolitan. A few species (e.g., Galapagos sharks) are wide-ranging but have disjunctions between populations. Management of species with allopatric or semi-isolated populations is of particular concern because they may be in danger of local extirpations (Burgess and Musick, 2005). Loss of genetic diversity and global population declines would be more difficult to reverse in these species than in those that are cosmopolitan.

There is growing concern over declines in shark populations as a result of pelagic and coastal fisheries. Estimating the magnitude of these declines is difficult due primarily to an overall lack of appropriate data sets. For pelagic sharks, the available data are primarily from commercial logbooks, which are notoriously incomplete and inaccurate; and observer data sets, which are extremely limited in scope. Very few fishery-independent data sets exist for pelagic sharks. Estimates of declines in the dominant sharks captured in pelagic fisheries in the western North Atlantic are typically 50-75% (Cortés et al., 2007) but are highly variable (Table 2).

Table 2.—Published estimates of changes in catch rates for pelagic sharks in the western North Atlantic Ocean according to Cortés et al. (2007).

Species	Cortes et al. (2007) Observer 1992-2005	Cortes et al. (2007) Logbook 1992-2005	Cortes et al. (2007) Logbook (G+C) 1986-2005	Baum et al. (2003) Logbook 1986-2000	Baum and Myers (2004) Survey Data 1950's vs 1990's
Blue shark	**52%↓**	**73↓**	**91%↓**	**60 %↓**	**n/a**
Mako sharks	**48 %↓**	**1 %↓**	**62 %↓**	**30 %↓**	**45 %↓**
Thresher shark	**99%↑**	**52 %↓**	**87 %↓**	**80 %↓**	**n/a**
Silky shark	**46 %↓**	**50 %↓**	**48 %↓**	**n/a**	**91 %↓**
Oceanic whitetip	**9 %↓**	**57 %↓**	**75 %↓**	**70 %↓**	**99 %↓**

Cortes et al (2007)

The World Conservation Union's (IUCN) Shark Specialist Group is tasked with assessing the status of all shark species for inclusion in the IUCN red list of Threatened Species (Fig. 3). Many of the pelagic shark species have recently been assessed. Some regional assessments have concluded that some species are in grave threat of extinction; however, these designations have been challenged and debated. For example, in the northwest Atlantic, oceanic whitetip sharks have been assessed as Critically Endangered (Baum et al., 2006); common and bigeye thresher sharks have been proposed as Endangered (Dulvy et al., 2008); and silky sharks have been proposed as Vulnerable (Dulvy et al., 2008). These assessments are based largely on analyses conducted in two highly publicized papers (Baum et al., 2003; Baum and Myers, 2004). These papers have been criticized for exaggerating and overstating the results from limited and inadequate data sets (Burgess et al., 2005). Cortés et al. (2007) cautioned that the status of pelagic shark stocks should not be assessed based on limited time series. Global designations of pelagic sharks are less contentious. Blue sharks are listed as globally Near Threatened (Stevens, 2000) and oceanic whitetip sharks (Baum et al., 2006) are listed as globally Vulnerable to extinction. It has been proposed that common thresher sharks, bigeye thresher sharks, and shortfin mako be listed as globally Vulnerable (Dulvy et al., 2008), and silky sharks as Near Threatened (Dulvy et al., 2008).

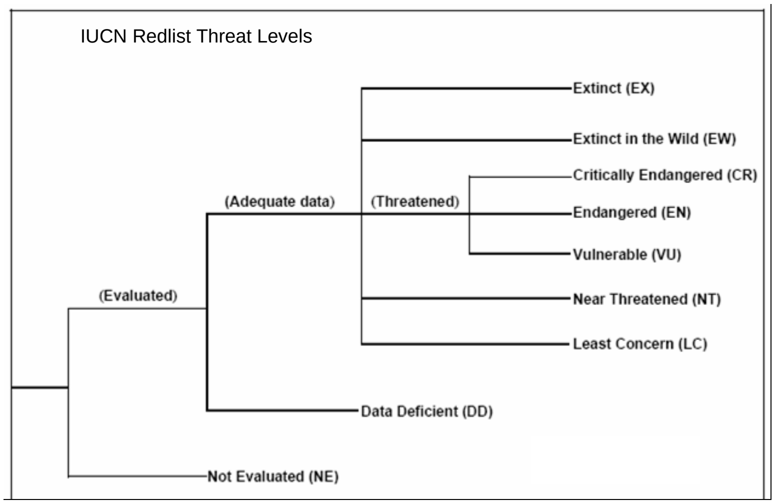

Figure 3.—Threat levels used in species assessments to be included in the IUCN red list of Threatened Species (IUCN, 2001).

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Sensory Systems in Elasmobranchs

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Elasmobranch fishes employ a variety of sensory modalities to detect and localize prey. Many elasmobranch sensory systems exhibit adaptations that differ from teleost fishes, and elasmobranchs also possess one sensory modality, the ampullae of Lorenzini, that is absent in marine teleosts. Like teleosts, olfaction is used to detect odorants that become entrained and transported, sometimes over long distances, and provide the shark with information from a distance. At closer range, the visual system enables the shark to track the prey until it moves close to the head. At this point, the lateral line and electrosensory systems are employed to enable the shark to position its mouth over the prey item for the final bite. This suite of exquisitely sensitive sensory systems provides the shark with the information necessary to successfully detect, localize and consume prey even when one or more senses are compromised (e.g., at night). By thoroughly studying the sensory systems of sharks, it may be possible to develop effective deterrents that would impact only the target elasmobranch species without affecting nontarget teleosts.

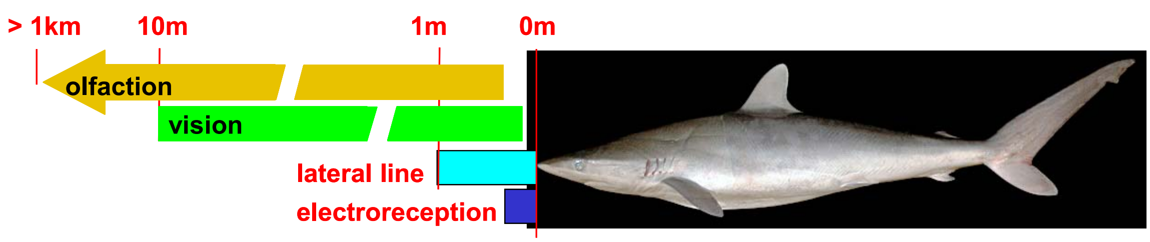

Figure 1.—Elasmobranch sensory systems and the range over which they play a role in behavior.

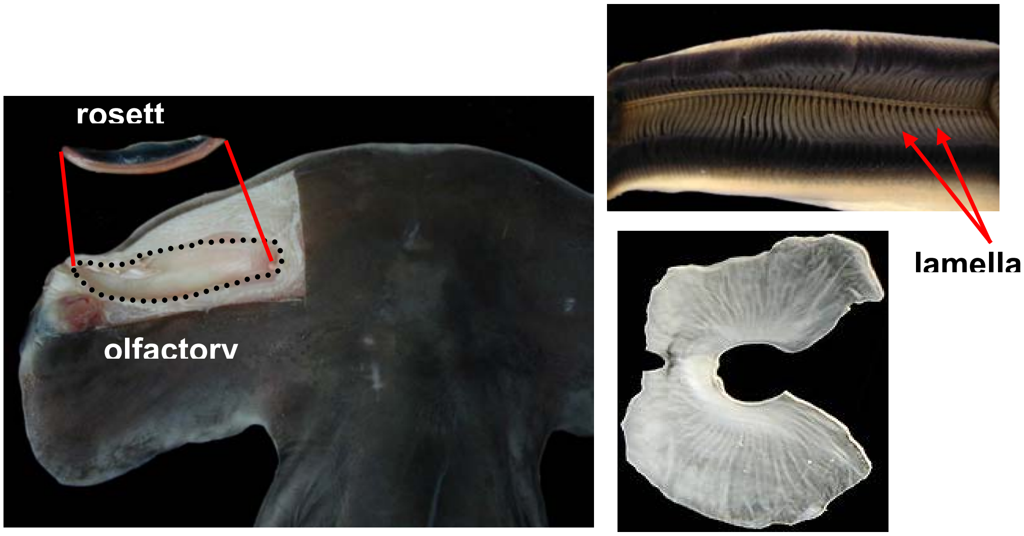

Figure 2.—The enlarged olfactory capsule of a hammerhead shark contains the olfactory rosette which is comprised of numerous lamellae. An individual lamella is overlain with an epithelium of supporting cells and olfactory receptor neurons.

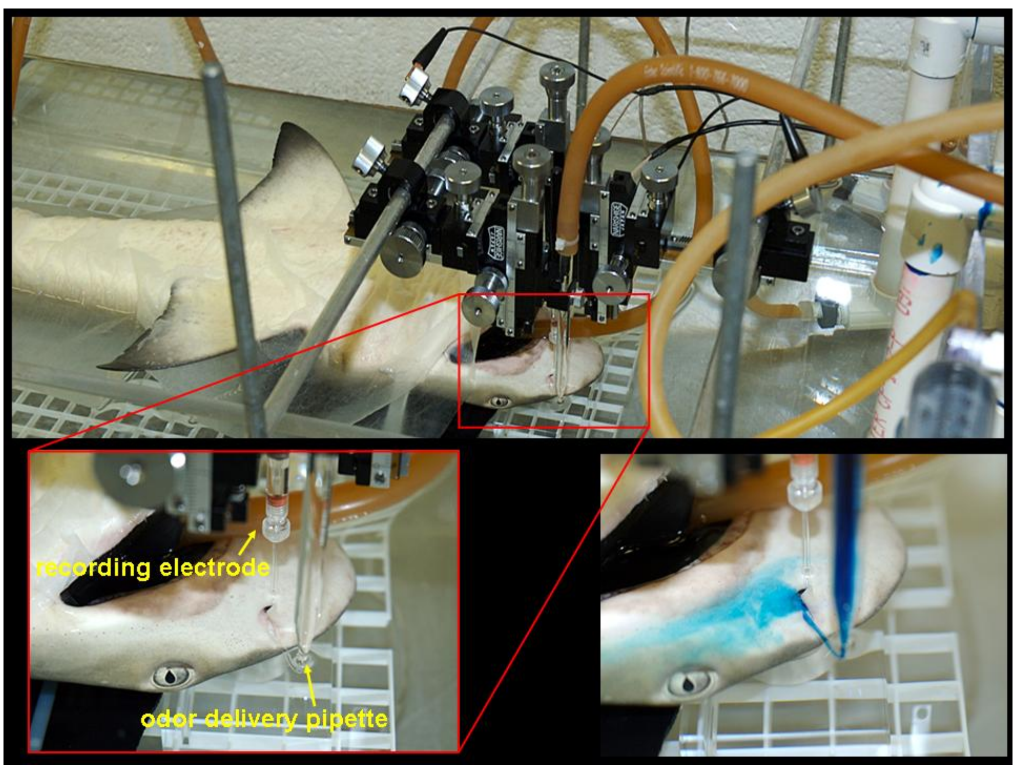

Figure 3.—The electro-olfactogram apparatus used to measure the response of sharks to an odorant.

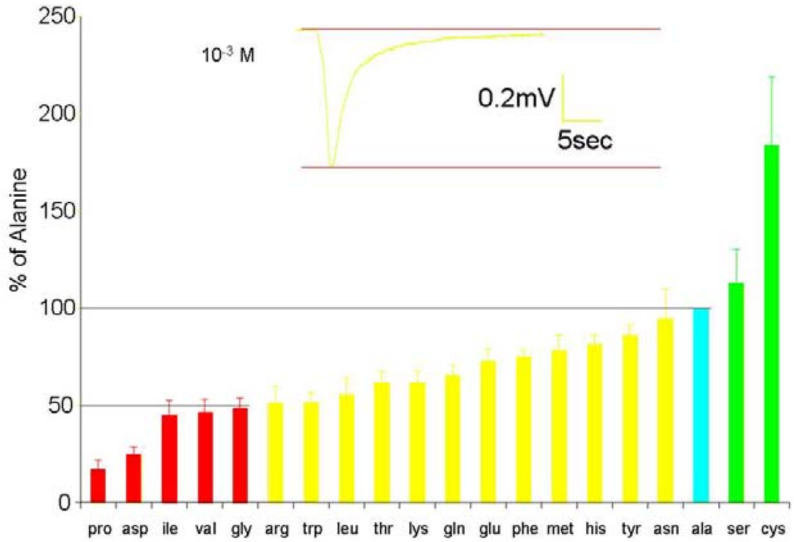

Figure 4.—Relative ranking of 20 amino acids expressed as a percentage of alanine for scalloped hammerhead sharks. The most stimulatory amino acid is cysteine and the least stimulatory is proline.

Table 1.—Threshold sensitivity to various amino acids determined for scalloped hammerhead sharks and compared to literature values for Atlantic stingrays and lemon sharks.

Species	Amino acid	Sensitivity threshold (Molarity)
Scalloped hammerhead	Cys	1.8×10^{-9} M
	Met	3.23×10^{-9} M
	Ala	8.0×10^{-11} M
	Asp	9.8×10^{-7} M
	Pro	2.6×10^{-6} M
Atlantic stingray	Ala	$10^{-7.8}$ M
	Met	$10^{-7.4}$ M
Lemon shark	Tyr	$10^{-11.9}$ M
	Met	$10^{-8.6}$ M
	Ala	$10^{-7.2}$ M
	Ser	$10^{-6.9}$ M

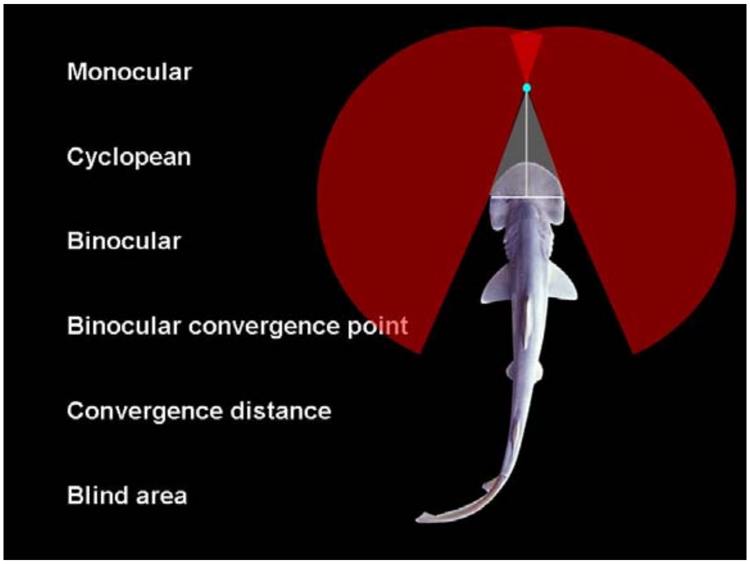

Figure 5.—The visual field is made up of the monocular field (field of view of a single eye), the cyclopean field (total field of both eyes combined), and the binocular field (field of overlap of left and right eyes). Other relevant points include the binocular convergence point (point at which binocular convergence is achieved), convergence distance (distance from the eyes at which binocular convergence is achieved) and blind area (area in which vision is occluded).

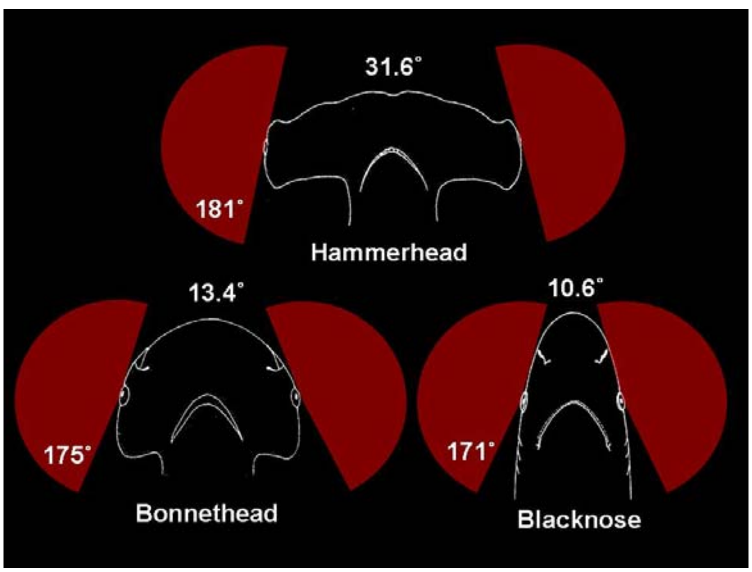

Figure 6.—Visual fields for scalloped hammerhead (*Sphyrna lewini*), bonnethead (*Sphyrna tiburo*), and blacknose sharks (*Carcharhinus acronotus*). The monocular visual field values are indicated in the visual field hemisphere to the left of each head, and the extent of the binocular field is indicated anterior to each snout. Whereas all sharks share similar monocular visual fields (171–181˚), the scalloped hammerhead has a much greater binocular overlap (31.6˚) than the other species.

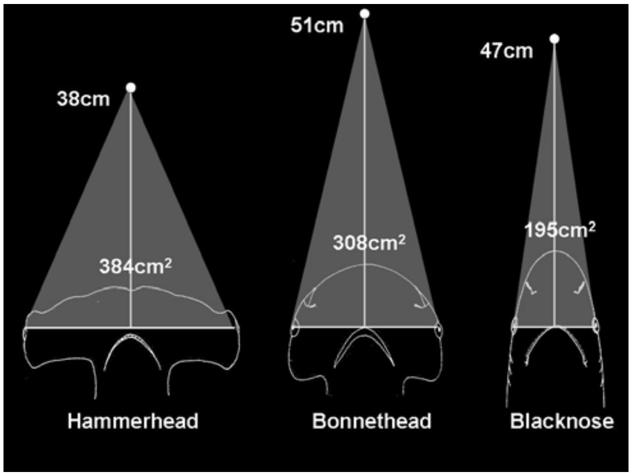

Figure 7.—Blind area and binocular convergence distance for scalloped hammerhead (*Sphyrna lewini*), bonnethead (*Sphyrna tiburo*), and blacknose sharks (*Carcharhinus acronotus*) after standardizing for shark total length. The scalloped hammerhead has the shortest binocular convergence distance of all three species (38 cm), but also has the greatest blind area (384 cm^2) because of the wide spacing between the eyes.

a

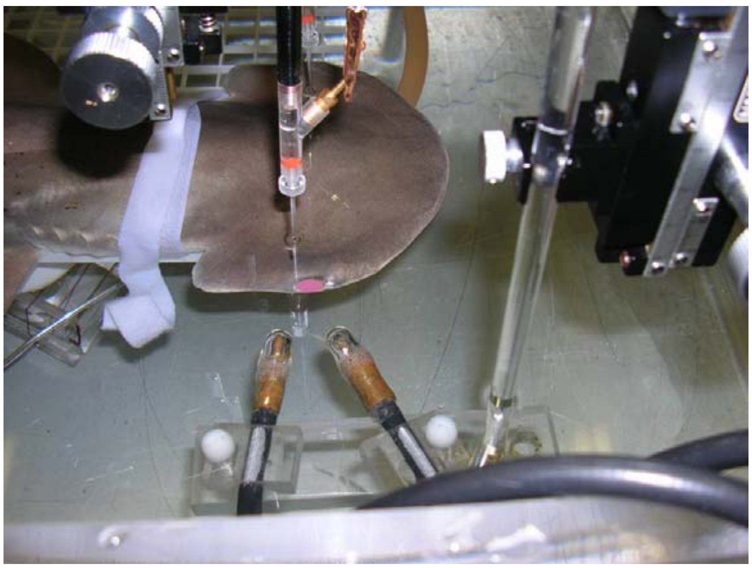

Figure 8.—The electro-retinogram apparatus used to measure the response of sharks to various wavelengths of light.

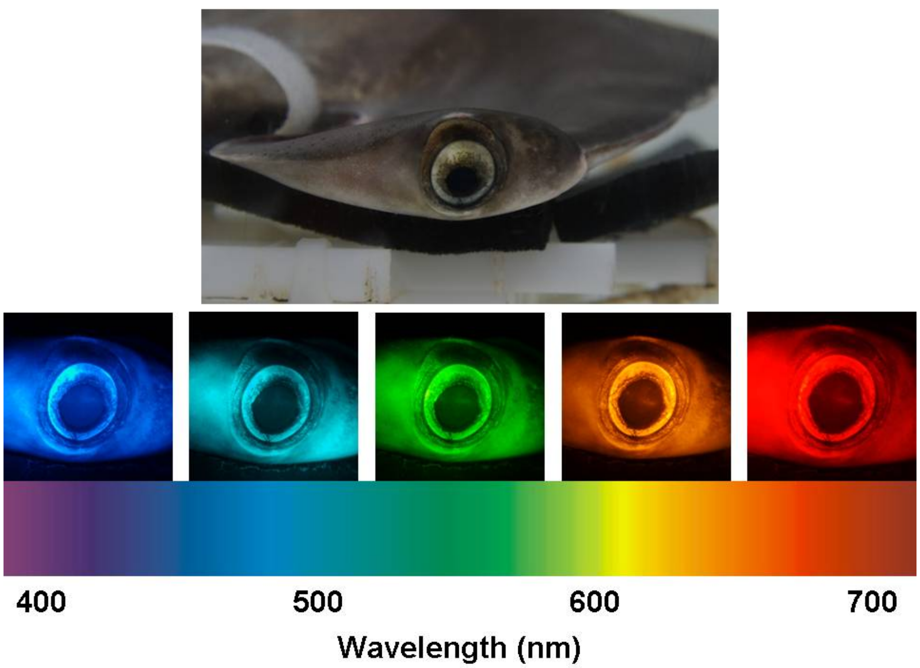

Figure 9.—The dilated pupil of a juvenile scalloped hammerhead shark under lab lighting (top) and when exposed to light of various wavelengths (bottom).

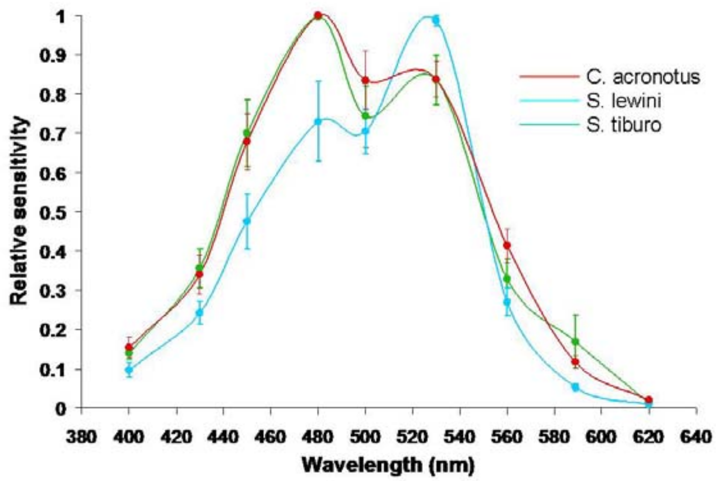

Figure 10. —Peak sensitivity to various wavelengths for three shark species.

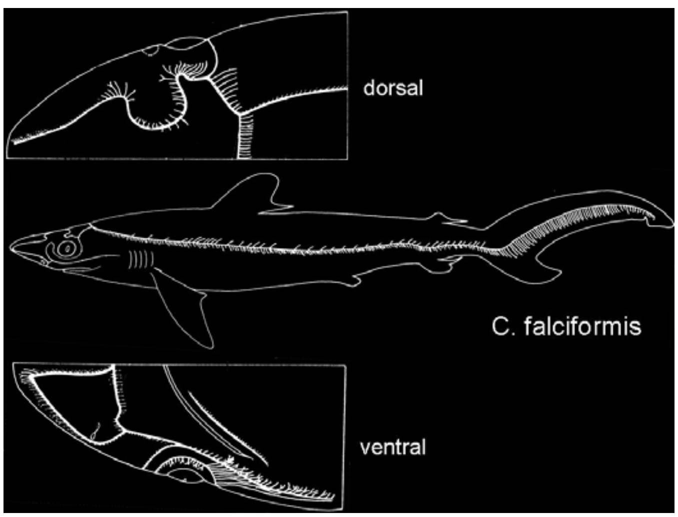

Figure 11.—Lateral line canals on a silky shark (*Carcharhinus falciformis*) showing trunk canals, and cephalic canals on dorsal (top) and ventral (bottom) surfaces of the head (modified from Tester and Kendall, 1969).

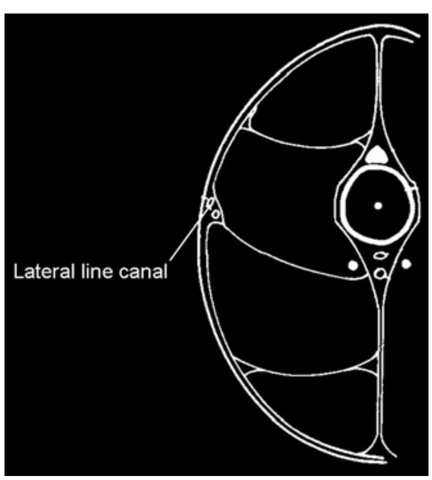

Figure 12.—Transverse section through a shark posterior to the anal fin showing the vertebral centra, epaxial and hypaxial musculature, and the subdermal lateral line canal.

Figure 13.—The lateral line system is located along the trunk of a shark and is clearly seen in this photograph of a juvenile scalloped hammerhead.

Figure 14.—Canal and superficial neuromasts on smooth dogfish (*Mustelus canis*), silky shark (*Carcharhinus falciformis*), and scalloped hammerhead shark (*Sphyrna lewini*) (modified from Tester and Nelson, 1967).

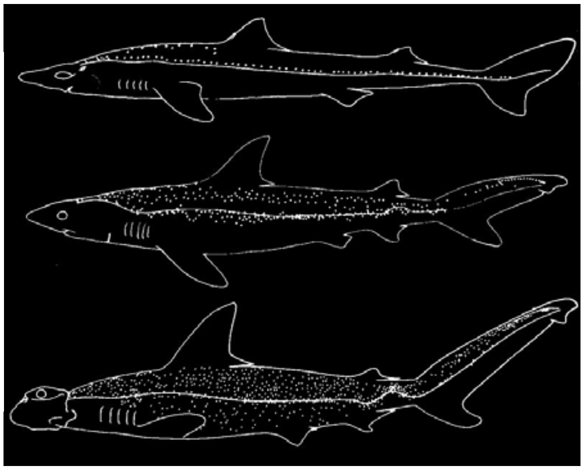

Figure 15.—Snout of a juvenile silky shark (*Carcharhinus falciformis*) showing the electrosensory pores. The pores surrounding the incurrent naris (red box at left) are magnified at right.

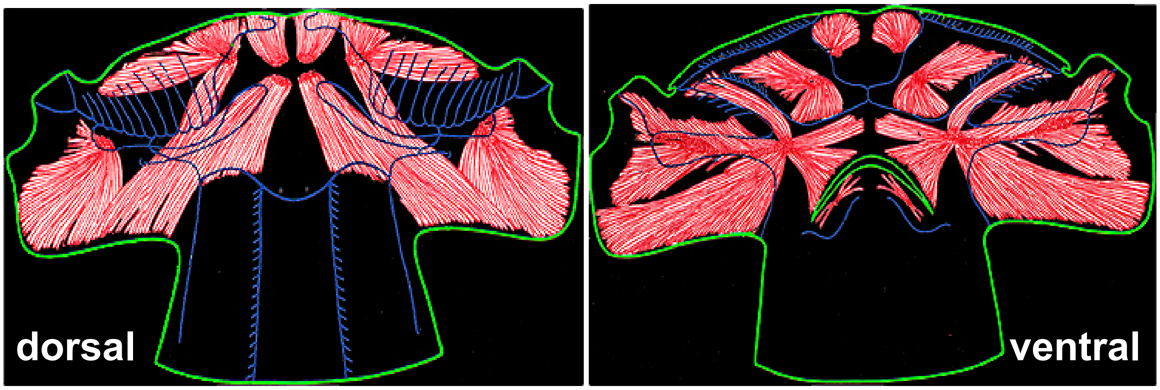

Figure 16.—Ampullary canals on the dorsal and ventral surfaces of the cephalofoil of a scalloped hammerhead shark (modified from Chu and Wen, 1979).

Figure 17.—Distribution pattern of electroreceptor pores on the dorsal surface of the head of a sandbar shark.

Table 2.—Total number of electrosensory pores from representatives of 12 shark species.

Species	Pore Count
S. acanthias	1262
S. squamulosus	1147
A. superciliosus	1291
A. pelagicus	1446
L. ditropis	444
G. cuvier	1046
P. glauca	889
R. terranovae	1736
C. brevipinna	1662
C. plumbeus	2317
S. tiburo	1932
S. lewini	3068

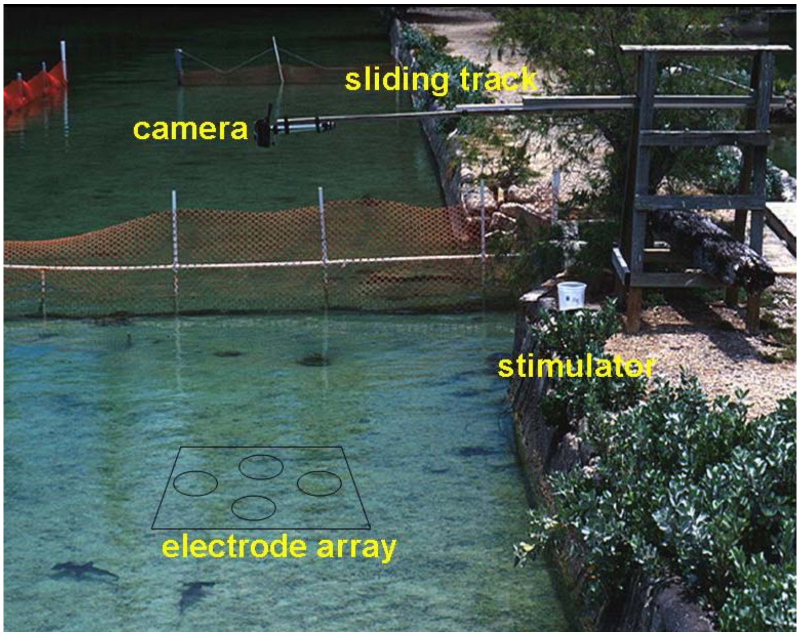

Figure 18.—Experimental apparatus used to study the response of scalloped hammerhead and sandbar sharks to prey simulating dipole electric fields. One of the four electrode pairs (circles on the acrylic plate) was activated with a weak electric current, which generated a dipole electric field around the electrodes. The response of the sharks was recorded with a video camera mounted onto the end of a sliding track and positioned directly above the center of the electrode array.

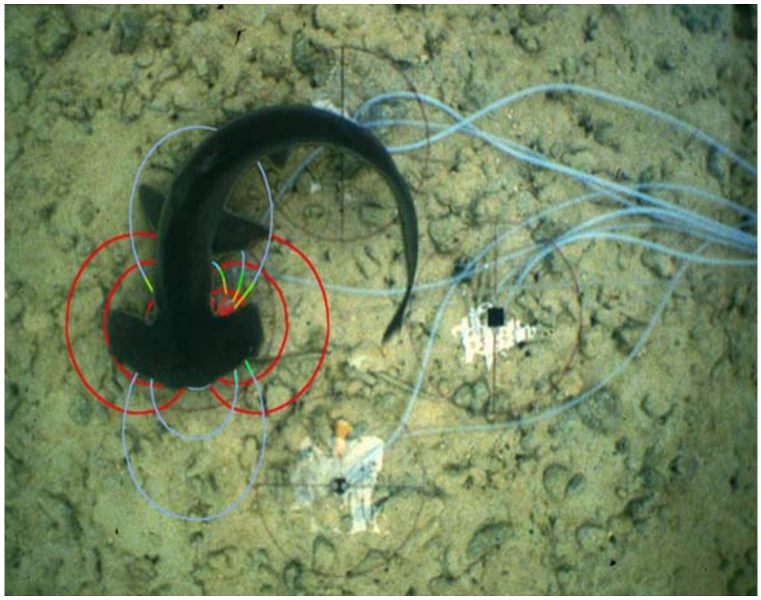

Figure 19.—A juvenile scalloped hammerhead shark turns sharply to bite at a prey-simulating dipole electric field. The electric stimulus is presented to one of four targets via salt-bridge electrodes (tubes on the right) under a clear acrylic plate. The concentric red ovals represent the electric field isopotentials.

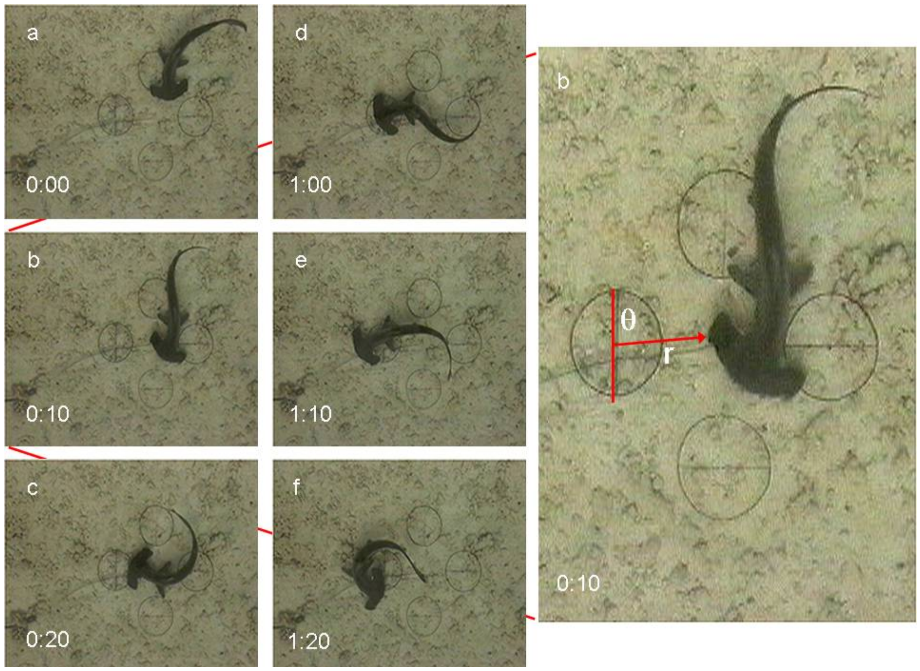

Figure 20.—Representative sample of a scalloped hammerhead shark orientation to a dipole electric field. (a) The shark is swimming within frame prior to orientation to the electric field. (b) The shark initiates an orientation to the dipole, and the distance (r) of the shark with respect to the center of the dipole and the angle (0) with respect to the dipole axis are measured (panel on right). (c) The shark swims towards the electrodes and (d) bites at the electrodes. After biting, the shark (e) swims away and (f) promptly turns back towards the electrodes. The counter in the lower left of each frame denotes the time in seconds.

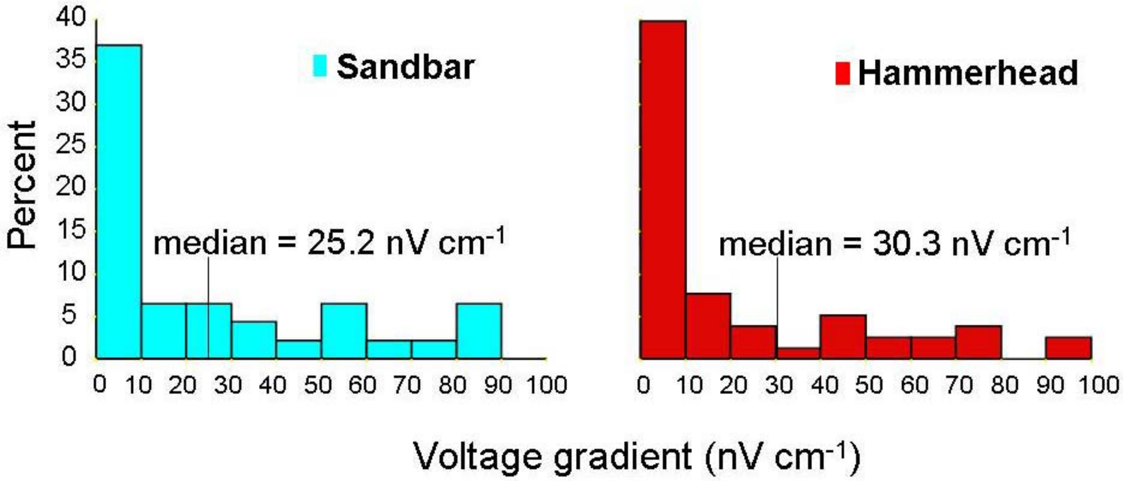

Figure 21.—Histogram of the percentage of orientations at electric-field intensities of < 1 mVcm^{-1}. Scalloped hammerhead sharks (*Sphyrna lewini*) and sandbar sharks (*Carcharhinus plumbeus*) demonstrate similar distributions across the entire range of field intensities. Approximately 70% of orientations were initiated to stimuli of < 0.1 mVcm^{-1} for both species, with few orientations requiring a higher field intensity to initiate a response.

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A Shocking Discovery: How Electropositive Metals Work and Their Effects on Elasmobranchs

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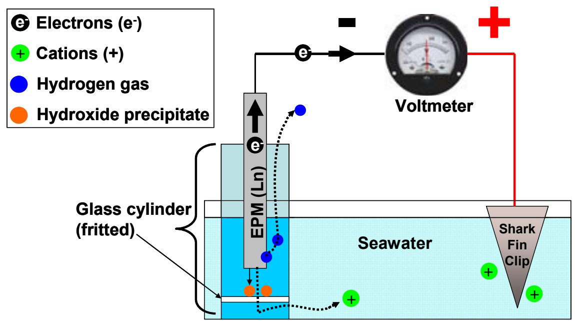
The multinational commercial pelagic longline fisheries that target tuna and swordfish but often catch sharks and rays as bycatch (Myers and Worm, 2003; Serafy et al., 2004; Tavares and Arocha, 2007) are substantial contributors to the fishing mortality of elasmobranchs. In the summer of 2006, while exploring the effects of rare earth magnets on sharks, researchers from Shark Defense Technologies, LLC discovered that electropositive metals had repelling properties on juvenile lemon sharks (*Negaprion brevirostris*). Electropositive metals (EPMs) reside towards the left side of the periodic table (including the lanthanide metals) and undergo spontaneous hydrolysis in the presence of seawater (Fig. 1). In addition to the hydrolysis reaction, lanthanides dissociate as trivalent cations. The hypothesized mechanism for elasmobranch repulsion occurs when the shark completes the circuit of a galvanic electrical cell. As the cations move towards the more electronegative shark, the voltage produced by this galvanic cell overwhelms the Ampullae of Lorenzini, which are sensitive to electrical voltages in the nanovolt (1×10^{-9} V) range. Subsequent tests with shark tissue (i.e, fin clippings) and a wide range of EPMs have generated voltages as high as 1.7 V, well beyond the electrical sensitivity of the Ampullae of Lorenzini. Elasmobranch tonic immobility bioassays suggest an increasing repulsive response correlated with the increasing reduction potential (standard electrode potential) of the metal (Figs. 2 and 3). Bioassays with teleost fish (e.g., cobia, *Rachycentron canadum*; Pacific halibut, *Hippoglossus stenolepis*) have suggested little repulsive effects when the fish are exposed to pure and alloyed EPMs. Therefore, more research incorporating strong EPMs or alloys to reduce elasmobranch bycatch during commercial fishing (Figs. 5 and 6) is recommended.



$$3H_2O(l) + 3e- \Rightarrow 3/2H_2(g) + 3OH- (aq)$$
$$Ln(s) \Rightarrow Ln^{+3}(aq) + 3e^-$$
$$Ln(s) + 3H_2O \Rightarrow Ln(OH)_3\downarrow + 3/2H_2(g)\uparrow$$

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Figure 1.—A schematic example of the galvanic cell created when EPMs (e.g., Lanthanum [Ln]), are submerged into water in the presence of an electronegative material (e.g., a shark fin clipping). When the EPM is submerged it undergoes spontaneous hydrolysis generating hydrogen gas (blue) and precipitating Ln hydroxide (orange). This results in a net positive charge (+) in the portion of the metal in contact with the water and a net negative charge (–) in the remaining EPM material. This separation of charge, resulting in a voltage potential, can be measured with a voltmeter connected to the EPM and the shark fin clip. The use of a glass cylinder, which provides a conductive passage for ions (similar to a salt bridge), ensures that precipitates formed during the process are isolated.

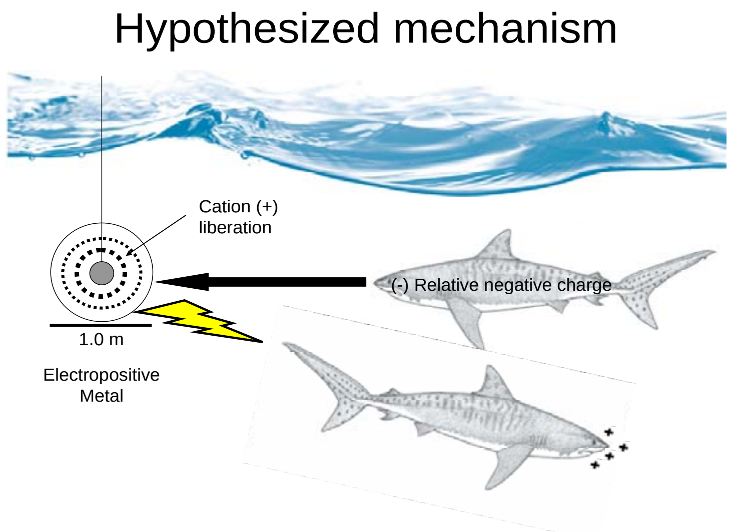

Figure 2.—Schematic of hypothesized mechanism showing cations liberated by the spontaneous hydrolysis of the electropositive metal in water flowing towards the more electronegative shark. As the cations move to the shark they generate a voltage which overwhelms the shark's electrical sensory mechanism causing it to be repelled.

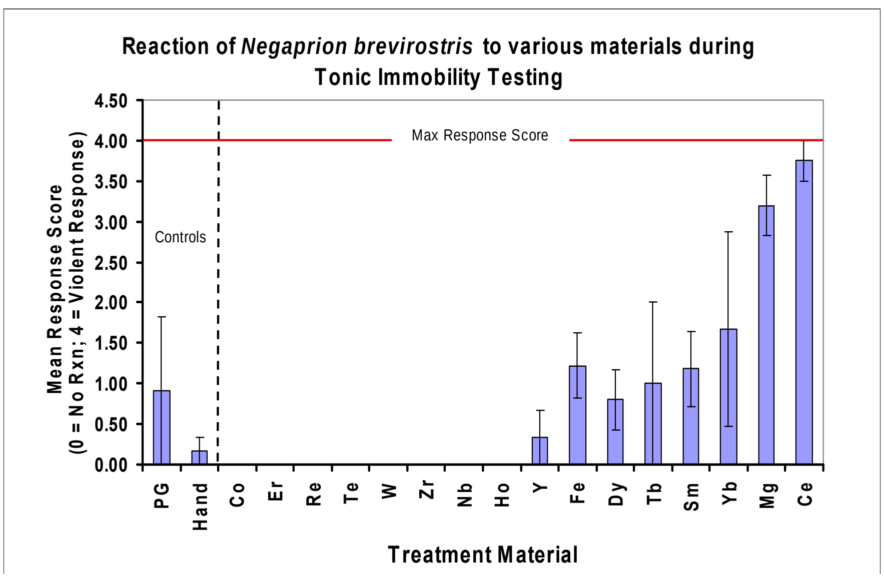

Figure 3.—Overall reaction of lemon sharks, *Negaprion brevirostris*, when exposed to various test materials during tonic immobility. PG = pyrolytic graphite; Hand = bare hand; Co = cobalt; Er = Erbium; Re = Rhenium; Te = Tellurium; W = Tungsten; Zr = Zirconium; Nb = Neodymium; Ho = Holmium; Y = Yttrium; Fe = Iron; Dy = Dysprosium; Tb = Terbium; Sm = Samarium; Yb = Ytterbium; Mg = Magnesium; Ce = Cerium.

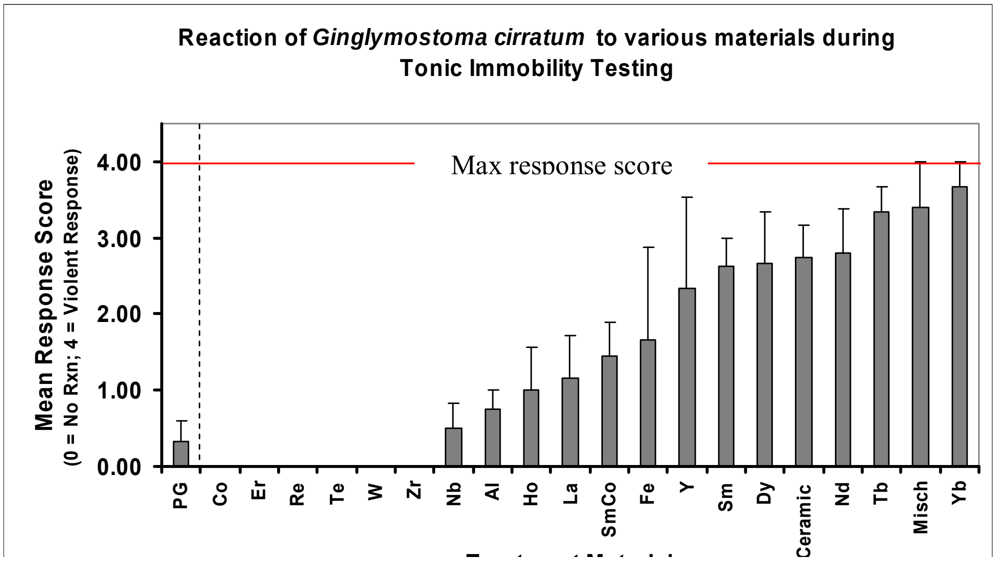

Figure 4.—Overall reaction of nurse shark, *Ginglymostoma cirratum*, when exposed to various test materials during tonic immobility. PG = pyrolytic graphite; Co = cobalt; Er = Erbium; Re = Rhenium; Te = Tellurium; W = Tungsten; Zr = Zirconium; Nb = Niobium; Al = Aluminium; Ho = Holmium; La = Lanthanum; SmCo = Samarium/Cobalt; Fe = Iron; Y = Yttrium; Sm = Samarium; Dy = Dysprosium; Ceramic = ceramic magnets; Nd = Neodymium; Tb = Terbium; Misch = mischmetal alloy; Yb = Ytterbium.

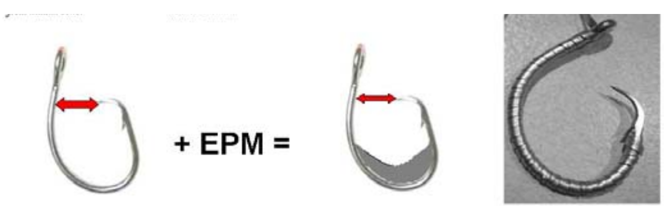

Figure 5.—Potential application of electropositive metals on a circle hook.

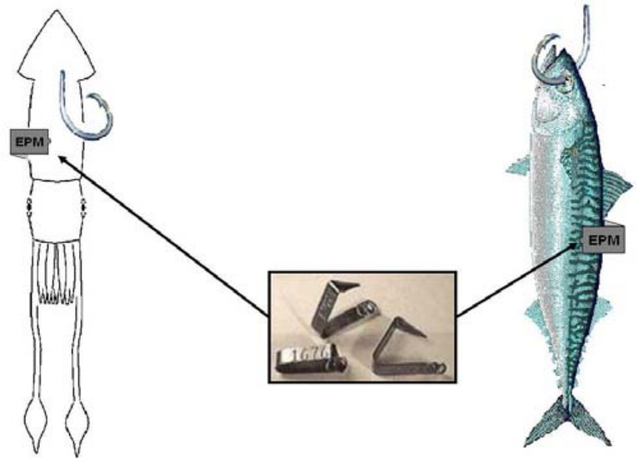

Figure 6.—Longline: Bait applications.

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Juvenile Sandbar Shark Aversion to Electropositive Metal

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Reducing shark bycatch in longline fisheries targeting tunas and swordfish is increasingly recognized as a priority because of the general inability of many of the world's shark populations to sustain high rates of fishing mortality. This study was conducted to measure changes in the behaviors of captive juvenile sandbar sharks (*Carcharhinus plumbeus,* Family Carcharhinidae) to the presence of small ingots of Praseodymium-Neodymium alloy. The research was conducted at the Virginia Institute of Marine Science's Eastern Shore Laboratory (Wachapreague, VA). Because of this facility's location adjacent to U.S. mid-Atlantic estuaries, juvenile sandbar sharks are readily available during the summer months. The sharks are easily captured using standard recreational hook-and-line fishing gear and do well once in captivity (Fig. 1).

Small ingots (2 cm × 2 cm × 10 cm) of Praseodymium-Neodymium (Pr-Nd) alloy clearly altered the swimming patterns of individual sharks and deterred feeding in groups of sharks. During the former experiments, individual sharks were maintained in a 3.6 m diameter × 0.67 m deep pool and their swimming patterns recorded over 1-hour intervals using a digital video camera. These records were subsequently digitized using Lolitrack automated video analysis software (Loligo Systems, Tjele, Denmark). Representative results are shown in Figure 2. (Because of the maximum height of the digital video camera imposed by the laboratory ceiling, small portions of the tank at the 12 o'clock and 6 o'clock positions were out of frame.) Sharks generally would not approach the three ingots of the Pr-Nd alloy (suspended in a vertical line immediately below the surface, at mid-depth, and near tank bottom) closer than 60 cm and spent significantly more time at the side of the tank opposite the position of electropositive alloy. In contrast, three lead fishing weights suspended at the same position caused no apparent alterations in swimming patterns (Fig. 2).

Likewise, in two separate experiments, a group of 14 sharks and a group of 7 sharks that were maintained in a large circular tank (7 m diameter × 1.8 m deep) would not attack pieces of cut bait suspended within approximately 30 cm of the alloy. This latter deterrent affect was transient, however, most likely due to social facilitation of feeding. The deterrent effect was apparent through approximately twice as many trials when seven sharks were present as when 14 sharks were in the tank.

Pr-Nd alloy clearly exhibits potential to repel sharks from longline gear, although optimal size and shape, distance to baited hooks, etc. remain to be determined. Other more electropositive alloys may be more effective but remain untried. Behavioral assays with captive juvenile sandbar sharks can clearly provide an effective stratagem for testing and optimizing the use of electropositive alloys as a shark bycatch reduction method prior to extensive at-sea trials.

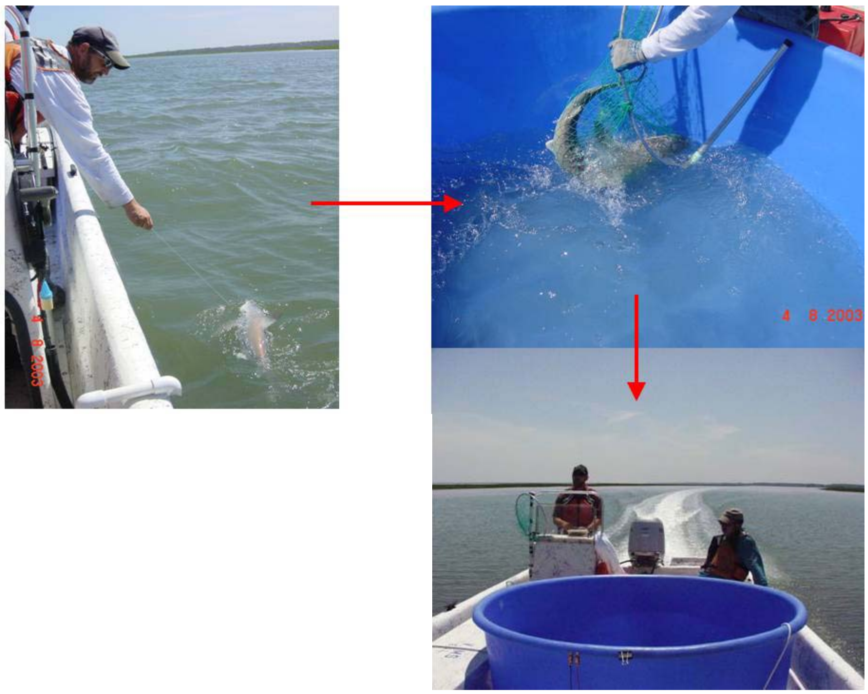

Figure 1.—Juvenile sharks (newborn to 4 years old) are readily accessible. They are easily captured by hook and line and transported, and readily adapt to captivity with zero mortality.

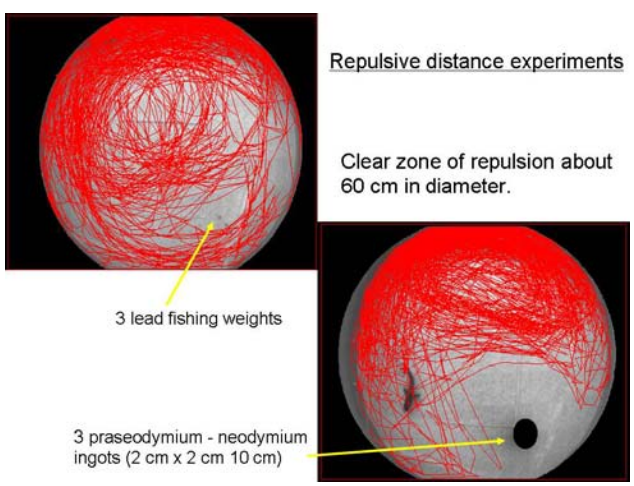

Figure 2.—Repulsive distance experiments.

Galapagos and Sandbar Shark Aversion to Electropositive Metal (Pr-Nd Alloy)

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Reports suggest that some shark populations such as scalloped hammerheads (*Sphyrna lewini*), oceanic whitetips (*Carcharhinus longimanus*), and tiger sharks (*Galeocerdo cuvier*) have decreased between 60% and 99% in certain regions (Baum et al., 2003; Baum et al., 2004). In several fisheries, it is common to have rates of shark bycatch exceed the capture rates of targeted fish species (Bonfil, 1994). The problem of shark and ray incidental capture is a major concern, in particular, because of their importance as predators at the top of the marine food chain. Removal of these predators not only affects the population structure of shark and ray species, but also indirectly affects the larger marine communities (Myers et al., 2007).

Understanding the sensory and behavioral ecology of sharks and rays are important components for developing strategies aimed at reducing shark and ray incidental bycatch. Elasmobranchs have an electroreceptive system (ampullae of Lorenzini) that is capable of detecting electric field strengths as low as 5 nV/cm (Haine et al., 2001). The weak electric fields generated by living organisms can be detected by these electroreceptors. This allows sharks and rays to locate their prey in the absence of any other sensory stimuli. In addition, very strong electric fields have been shown to deter approaching sharks. Sharks are most likely perturbed by the large electric fields that may overload their electrosensory modality. Unfortunately, the devices that generate large electric currents are not suitable for use in most fisheries because of their size and power requirements.

A possible alternative to these electronic shark deterrent devices is to use highly electropositive metals (e.g., lanthanide metals). Electropositive metals have a strong tendency to release electrons and generate large oxidation potentials when placed in seawater. It is thought that these metals perturb the electrosensory system in sharks and rays, causing the animals to exhibit aversive behaviors. Recent experiments with small sharks held in a tonic immobile state indicate that sharks bend away or even break their tonic state when the electropositive metals are brought close to their heads (Eric Stroud, pers. comm.). It is not known whether these results will translate to a change in feeding behavior of freely swimming sharks.

We conducted experiments to test the ability of electropositive metals to deter sharks from feeding on bait. Using a shark-viewing cage, we conducted paired choice experiments to examine the feeding behaviors of Galapagos sharks (*Carcharhinus galapagensis*) and sandbar sharks (*Carcharhinus plumbeus)*. Experiments were conducted in shark viewing cages off the coast of the North Shore of Oahu, Hawaii. These cages allowed the experimenter to observe and film shark behaviors as the sharks approached and attacked bait on the ends of wooden poles (Fig. 1). Experiments consisted of paired trials in which two fish were placed outside of the shark cage. The fish were attached to the ends of two different wooden poles. At the end of each pole was either a piece of Pr-Nd (praseodymium-neodymium) electropositive alloy cut into a 5 cm × 2.5 cm × 0.64 cm piece or a lead fishing weight of approximately the same size, serving as a visual control. The poles were spaced 1.5 m apart and placed outside of the cage simultaneously. This allowed sharks to approach the poles and eat one of the two baits. The first bait that was eaten was noted, and the sharks' approach and feeding behavior were videotaped. We combined our data from both Galapagos sharks and sandbar sharks.

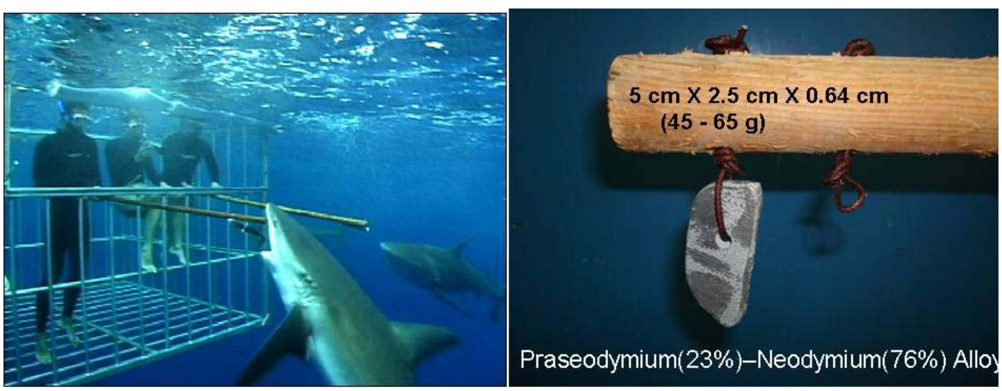

Figure 1.—Experiments with free-swimming, wild sharks were conducted from shark observation cages deployed off the North Shore of Oahu, Hawaii to determine how the presence of Pr-Nd metal alloy affects the feeding behavior of sharks.

We completed 16 trips to the North Shore in which we conducted paired trials (displaying two treatments simultaneously). Out of the 16 trips we carried out 77 trials – with 58 trials ending when the bait associated with a control metal was eaten first and only 19 trials ending when the bait associated with E+ metal was eaten first (see Fig. 2). When broken down by bait eaten per trip and analyzed using the Wilcoxon paired sample test, we have a significant difference between the two treatments ($p < 0.001$) in which there were 3.6 first bites on the control bait and 1.2 bites on the experimental bait (adjacent to the Pr-Nd alloy).

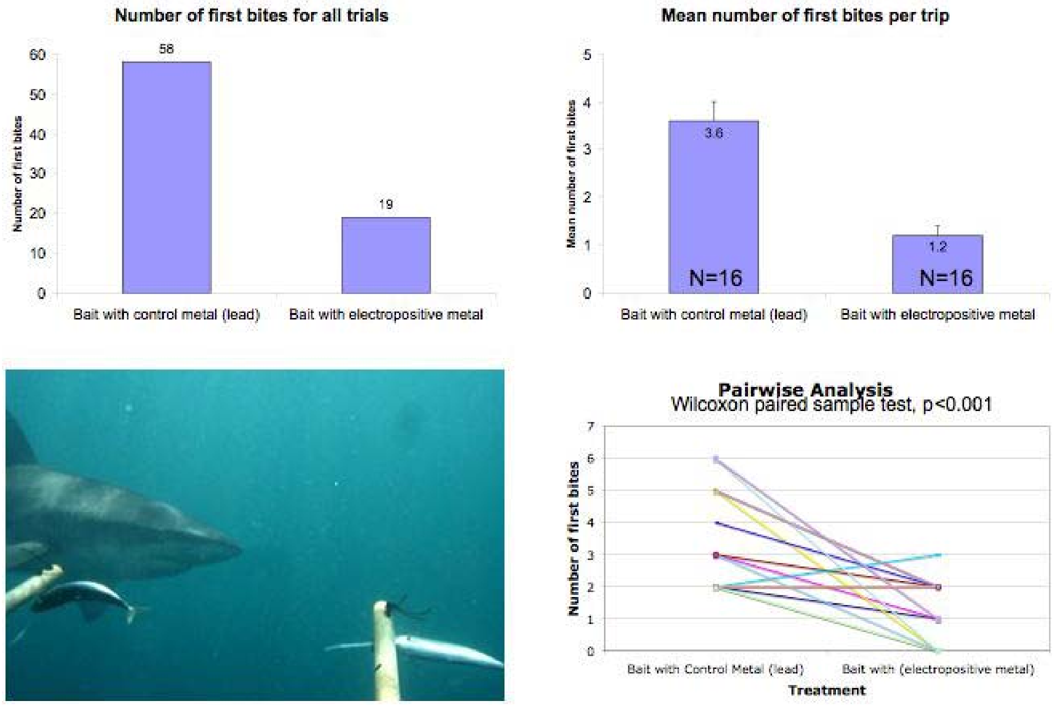

Figure 2.—The number of first bites for all trials and for each trip. Analysis with the Wilcoxon paired sample test indicates a significant difference ($p < 0.001$) between the two treatments indicating that the presence of the metal reduced the number of times bait associated with the Pr-Nd metal was eaten.

In addition to monitoring which bait was eaten first, we also examined the behavior of the sharks as they approached each pole. When sharks approached the pole with the Pr-Nd alloy, they often exhibited aversion responses in which the animals would make sharp turns away, attempt to stop, and cease biting attempts on the bait. We analyzed the number of aversion responses as the shark approached the two bait treatments. Figure 3 shows the total number of aversion responses exhibited at each bait treatment and also shows the mean number of aversion responses for each treatment during a trip. Analysis with the Wilcoxon paired sample test indicates a significant difference in number of aversions between the two treatments ($P < 0.01$).

Analyses of feeding trials were conducted by combining interactions with Galapagos and sandbar sharks. Separate analysis of each species shows that Galapagos sharks significantly bite bait associated with lead controls first. In addition, Galapagos sharks exhibit significantly more aversion responses when approaching bait associated with the Pr-Nd alloy. We had fewer interactions with sandbar sharks, but in both assays behavioral trends paralleled those of the Galapagos sharks.

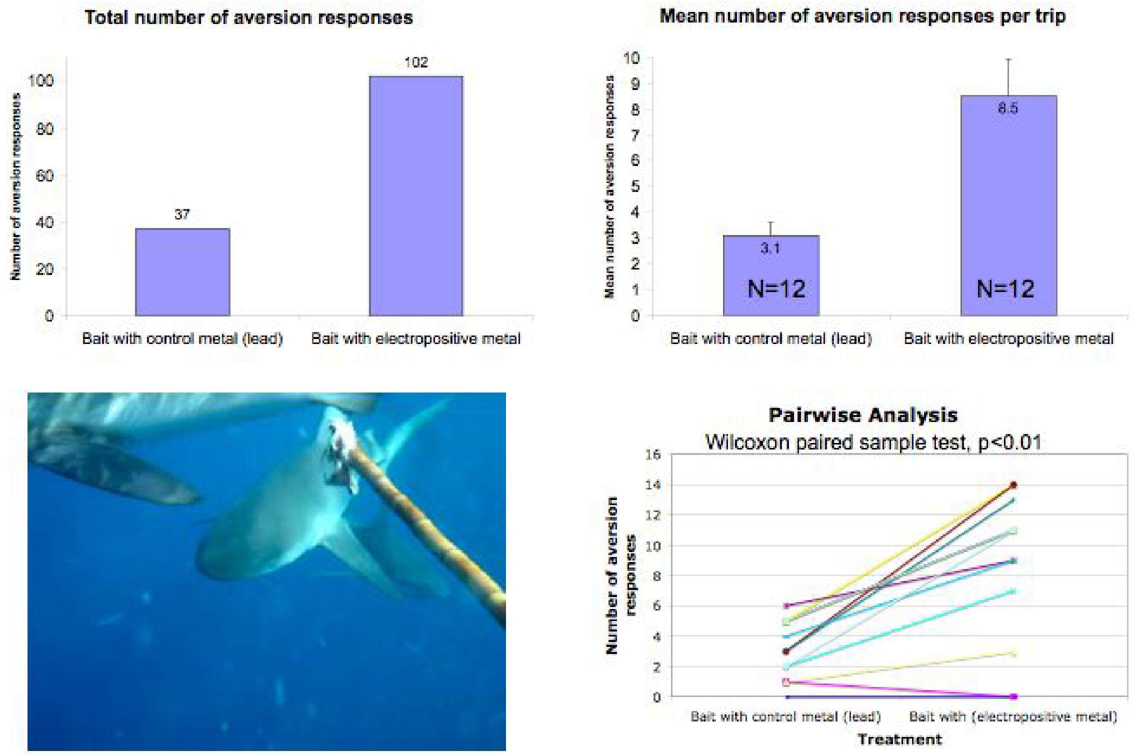

Figure 3.—Aversion responses during all shark interactions and the mean number of aversion response for each trip. The Wilcoxon paired sample test indicates a significant difference ($p < 0.01$) between the two treatments indicating that the presence of the metal increased the number of aversion responses exhibited as the animals approached the bait.

Results indicate that the opelu bait (*Decapterus macarellus*) associated with the lead control metal was eaten preferentially to bait associated with an electropositive metal (Pr-Nd alloy). In addition, Galapagos and sandbar sharks exhibited more aversion behaviors as they approached bait associated with the electropositive metal. Taken together, these results indicate that lanthanide alloys influence feeding behavior in these two species of sharks and could be potentially used to reduce the incidental capture of other shark species in longline fisheries.

Additional directions for this work include several research priorities. Most importantly, we need a better understanding of the cues generated by these metals when placed in seawater. Examining the electrochemical properties of E+ metals by measuring the electric fields and galvanic currents created under different physical parameters, such as different salinity and temperature regimes, would help provide an initial assessment of what the sharks may be sensing. We also plan to continue conducting paired feeding assay trials to assess different metal alloys and different combination of metals. We will conduct captive shark studies to examine how different behavioral states, intraspecific competition/social facilitation, and habituation to the metals impact aversion responses of sharks to lanthanide metals. We also will conduct fishing experiments in the field to examine impacts on shark catch-per-unit-effort.

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Rare Earth Elements: A Current Market Overview

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Rare earth elements (REE), or lanthanide metals, are being increasingly used in a variety of industrial applications because of their unique properties. China possesses the world's largest reserves of REEs (approx. 52% of world's total). China is currently the largest producer as well as consumer of REEs and also the largest exporter, currently supplying 90-95% of the world's consumption. Chinese policies have considerable impacts on the availability and pricing of REEs. It was concluded that the availability of material for the application of shark deterrence should not be a significant concern.

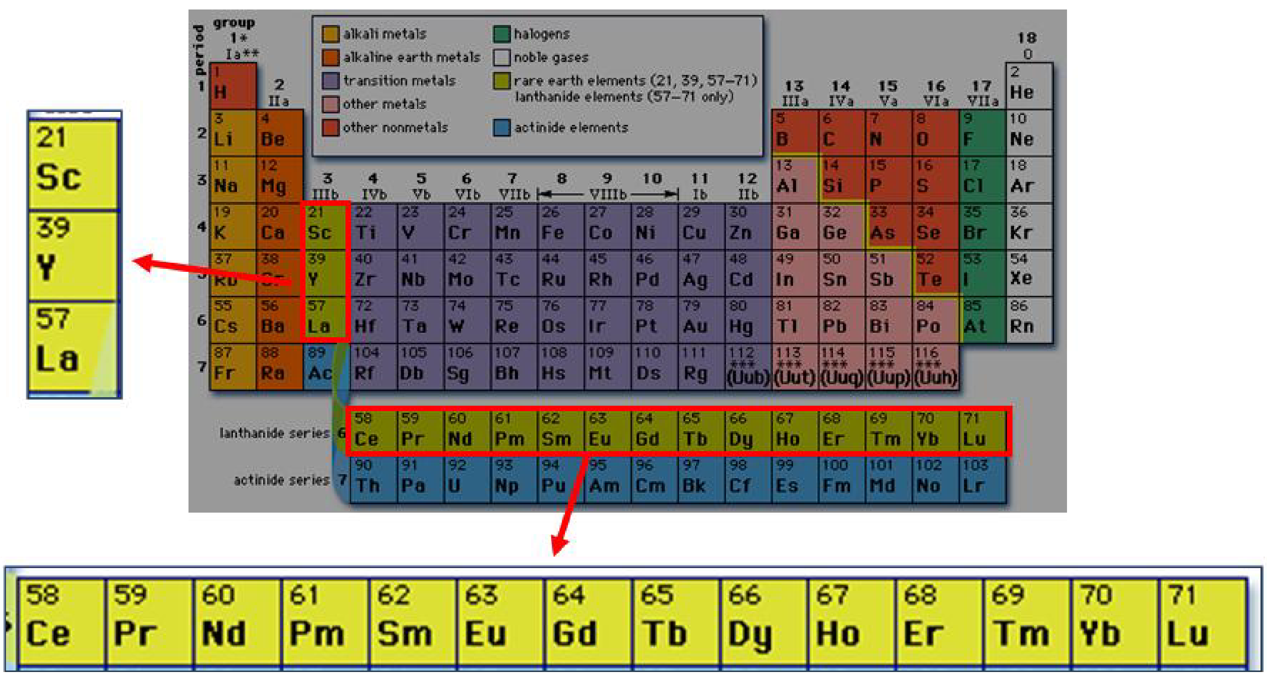


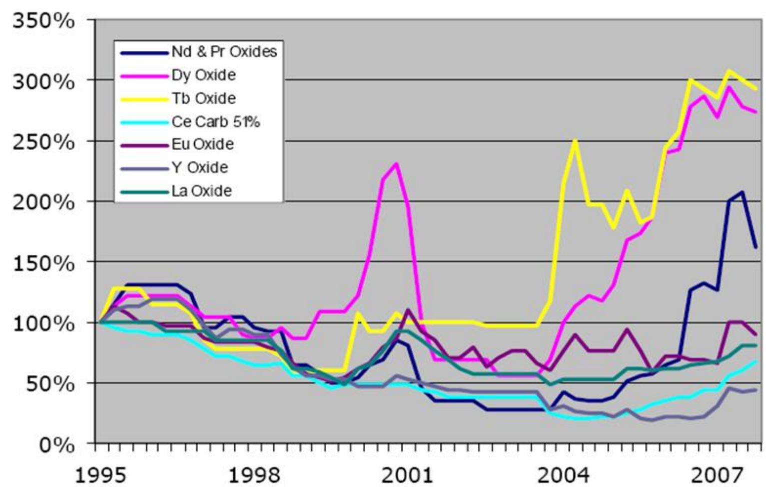
Figure 1.—The industry study of REEs; Understanding China (Chinese Policy) is integral to understanding the REE Industry and REE prices.

Table 1.—2006 Global Rare Earth Consumption (tonnes, rare earth oxides ±10%; IMCOA, 2007).

Rare Earth Elements:
Applications

Application	China	Japan & SE Asia	USA	Europe	Other	Total
Catalysts	6,500	3,500	6,000	5,000	500	21,500
Glass	7,250	3,500	1,000	1,000	250	13,000
Polishing	7,000	4,500	1,000	1,000	500	14,000
Alloys	10,250	4,000	1,500	1,000	250	17,000
Magnets	14,000	5,000	750	500	250	20,500
Phosphor	4,500	2,750	500	500	250	8,500
Ceramics	2,000	2,000	1,000	500	negligible	5,500
Other	6,500	1,000	250	250	negligible	8,000
Total	**58,000**	**26,250**	**12,000**	**9,750**	**2,000**	**108,000**

Rare Earth Elements:
Statistics & Trends



Source: Neo-Material Tech.

Figure 2.—Price history for key Rare Earth Materials 1995–2007 ($US).

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All references came from presentations previously given at the Third International Rare Earths Conference (2007, Hong Kong). The IMCOA presentation was provided by Dudley J. Kingsnorth from the Industrial Minerals Company of Australia (IMCOA) and the price graph was present by Constantine Karayannopoulos, President and CEO Neo Material Technologies Inc. (Title: *Trends & Challenges in the Global Rare Earths Industry*).

Sensory Systems in Elasmobranchs and Electric Field Measurements of E+ Metals

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Lanthanide metals and alloys are reactive in seawater and produce a measurable electric field that may be repulsive to electroreceptive fishes such as sharks. By measuring the electric fields of the metals, it is possible to understand what characteristics are responsible for this electrorepulsion and thus simulate those characteristics to deter sharks from biting.

The electropositive nature of lanthanide metals (Fig. 1) may make them suitable for use as potential shark repellents which can reduce shark bycatch on longline fishing gear. By attaching samples of lanthanide metals near the hooks (Fig. 2), the electric field generated may deter the sharks from biting. The requisite to understanding how the lanthanide metals affect shark sensory systems is the quantification of the electric field characteristics generated by these elements and alloys in seawater.

To measure the electric field around the metals, an acrylic tank is filled with seawater at a known temperature, salinity and conductivity (Fig. 3). A nonpolarizable bipolar Ag/AgCl electrode is positioned in the seawater 0.5 cm above the bottom of the tank. A reference electrode is affixed to the side of the tank as far as possible from the site of measurement. Output from the electrodes is filtered, differentially amplified, digitized and simultaneously monitored and stored on computer. A metal sample of known weight is placed on the bottom of the tank at a distance of 1 cm from the tip of the electrode. The voltage at the electrode tip is determined in the tank and the sample moved incrementally 1 cm away from the electrode and the voltage remeasured. This procedure is applied to a fishing hook, a sample of Nd, and a sample of Nd-Pr alloy. The measured voltage is plotted against distance for all three samples. Based on these results, it is possible to calculate a model of best fit for electric field intensity for the various metals.

The ability to accurately model an electric field in seawater has previously been demonstrated to provide predictive power. Sharks are known to orient toward and bite at the natural bioelectric field generated by their prey (Fig. 4). The bioelectric prey field can be simulated by a weak electric dipole that can be easily modeled to predict charge distribution in a conducting seawater medium (Fig. 5). The prey-simulating dipole field elicits the same feeding response in the sharks as the natural prey. The modeled values of the simulated field are closely matched by empirical measurement, thus providing confidence in the predictive power of the model (Fig. 6).

The results obtained in this study demonstrate the proof of concept that electric fields can be accurately measured in seawater. These data provide a baseline measure of what electric stimuli are attractive and repulsive to sharks, which can aid in the construction of an electric stimulator to simulate the e-field produced by the metals. In addition, these preliminary data have predictive power for how other lanthanide metals will likely react when exposed to a conductive seawater environment.

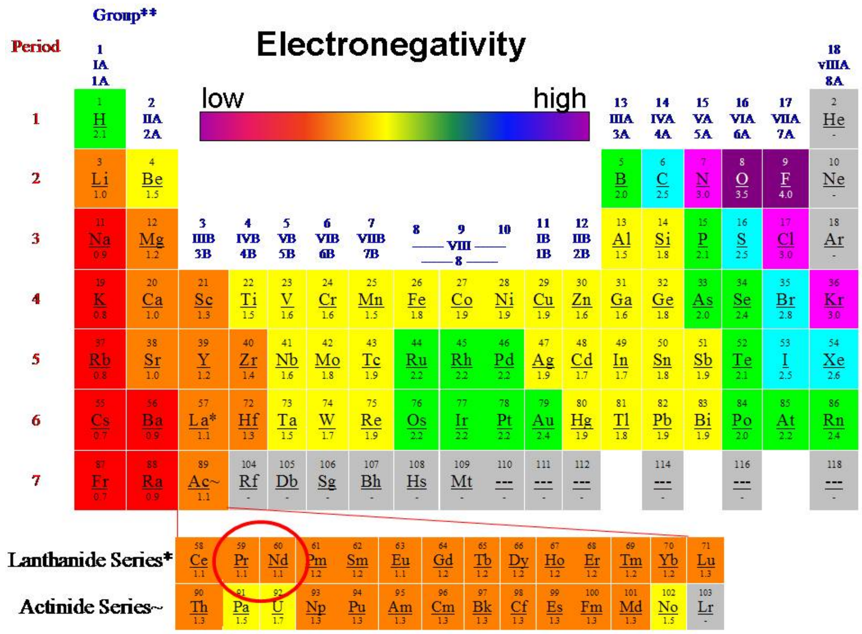

Figure 1.—Periodic table of the elements with graded ratings of electronegativity, which is the inverse of electropositivity. Electronegativity represents the element's ability to collect electrons, and electropositivity represents the element's ability to donate electrons in the formation of covalent bonds. Electronegativity generally increases with period and decreases down groups with lowest electronegativity (i.e., highest electropositivity) in the lower left near Francium and highest electronegativity (i.e., lowest electropositivity) in the upper right near Fluorine. Strongly electropositive elements have the potential to generate electric fields that may be a deterrent to sharks.

Figure 2.—Example of how a rare earth metal alloy is deployed on a long line circle hook to present an electric field in seawater sufficient to deter sharks from biting at the bait on the hook. The Nd-Pr alloy generates a measurable electric field in seawater. However, the close proximity of the Nd-Pr alloy to a stainless steel cable leader and a galvanized steel circle hook presents the challenge of numerous potential galvanic interactions.

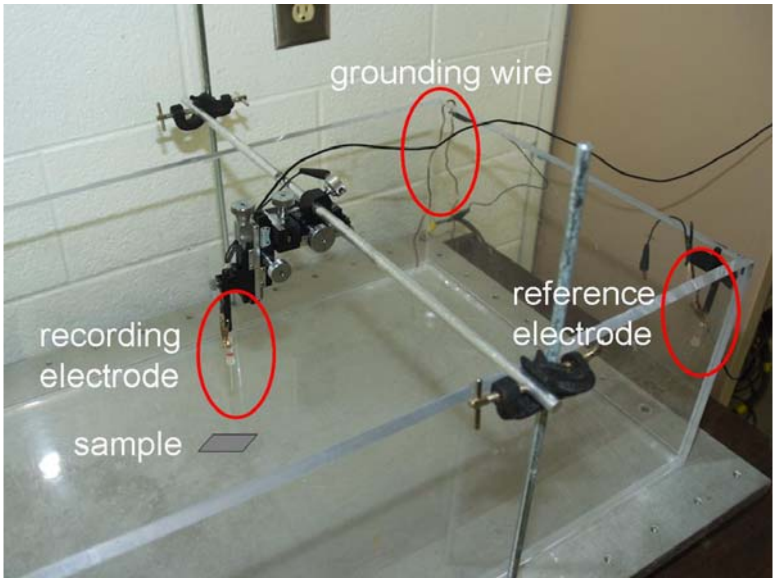

Figure 3.—To measure the electric field generated by rare earth metals in seawater, an acrylic tank is filled with seawater and a sample of metal is placed in the bottom of the tank. A recording electrode is secured with a micromanipulator and positioned to measure the voltage at various locations around the sample. A reference electrode affixed to the side of the tank as far as possible from the sample provides the inverting signal to a differential amplifier. A grounding wire in the seawater eliminates extraneous electrical noise.

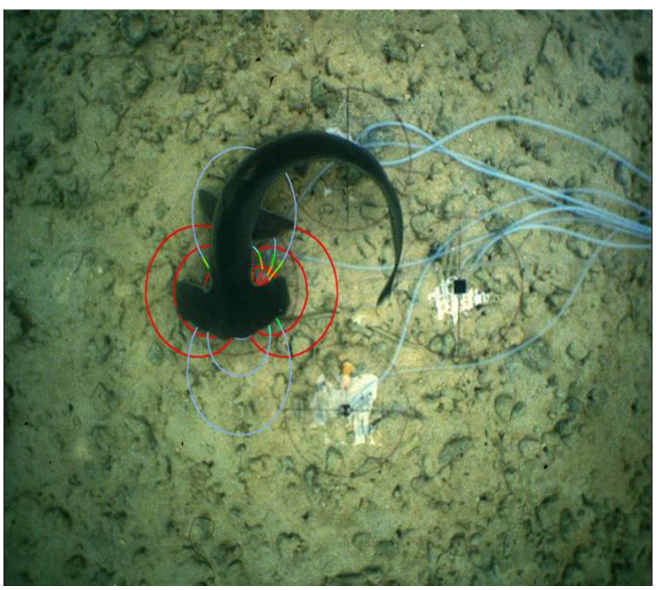

Figure 4.—A juvenile scalloped hammerhead shark turns sharply to bite at a prey-simulating dipole electric field. The electric stimulus is presented to one of four targets via salt-bridge electrodes (tubes on the right) under a clear acrylic plate. The concentric red ovals represent the electric field equipotentials. Sharks orient from a greater distance both at greater applied current and when the gap between the positive and negative poles of the dipole are spaced farther apart, mimicking a larger prey item.

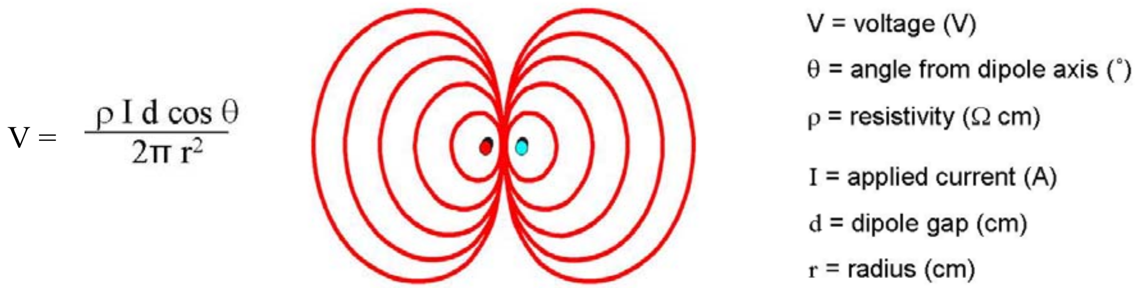

Figure 5.—The charge distribution of a dipole electric field is modeled by the equation: $V = \left(\dfrac{\rho I d \cos\theta}{2\pi r^2} \right)$. The variables include: ρ = resistivity of the seawater (Ω cm), I = applied electric current (A), *d* = electrode separation distance (i.e., distance between positive and negative poles of the dipole) (cm), *r* = radius (i.e., distance from the center of the dipole to the position in space for which the potential is being calculated) (cm) and θ = angle from the position in space to the center of the dipole with respect to the dipole axis. From this equation, it is apparent that the voltage (V) varies as an inverse square of distance (*r*). The voltage also varies as a function of angle with respect to the dipole axis, being maximal in the plane of the dipole axis (0°) and decreasing as a cosine function to a theoretical null in the perpendicular plane (90°). This equation describes the voltage in half space, with the electrodes mounted to the base of an insulating plate such that the conducting medium is a hemisphere above the electrodes. In a conducting medium in which the electric field can propagate freely in all dimensions, the voltage values would be halved.

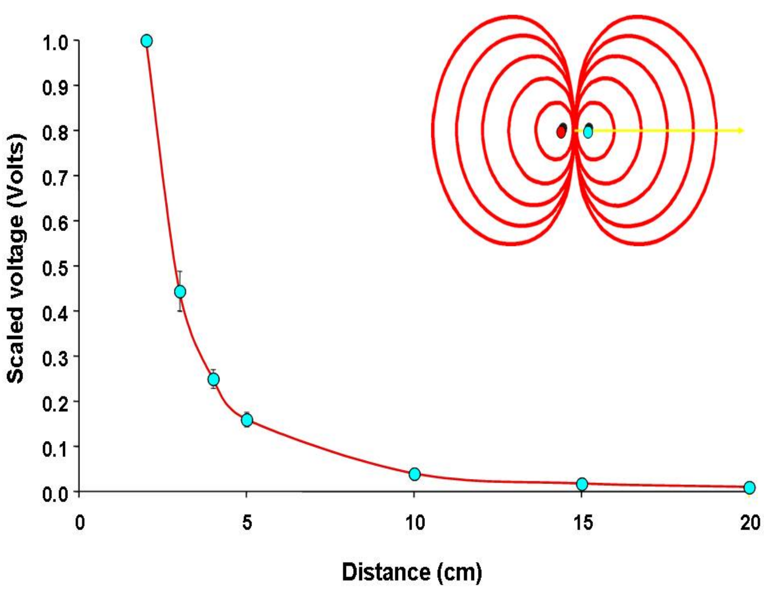

Figure 6.—Measured values (mean ± SD) of the voltage plotted with the calculated theoretical values for a dipole in a conducting medium. The voltage decreases as a square of distance and also decreases as a cosine function from a maximum at 0º to a minimum at 90º. The modeled values (line) closely fit the measured values (symbols) and are contained within the standard deviation error bars. The measurements were taken along the dipole axis at 0˚. Inset shows voltage equipotentials for a dipole source.

A Small Demonstration of Rare Earth Galvanic Cell

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On May 1, 2006, Shark Defense Technologies, LLC discovered an unusual effect of lanthanide metals on shark behavior—immobilized juvenile lemon sharks bended away from these metals when the metals were presented near their noses. After confirming no magnetic signature was present using sensitive milligausmeters, the phenomenon was labeled an electrochemical repellent.

Highly electropositive metals, particularly the early lanthanides and certain Groups I, II, and III metals, produced violent aversive reactions in juvenile lemon sharks (*Negaprion brevirostris*) and juvenile nurse sharks (*Ginglyostoma cirratum*). Pure electropositive metal ingots ranging from 70 g to 100 g terminated tonic immobility in juvenile lemon sharks and juvenile nurse sharks at distances of 2 cm to 20 cm despite lack of a visual cue. The most violent reactions using Group III metals were observed using Praseodymium, Lanthanum, and Cerium. Of the Group II metals studied, Magnesium, Calcium, and Strontium produced the most violent reactions, with Magnesium being the most stable and practical metal from this group for prolonged use. Group I metals are too reactive to be considered practical; however, Lithium produced a violent response in one juvenile lemon shark. In a closed system containing seawater electrolyte, an electropositive metal anode, and a shark fin clipping as the cathode, electromotive forces of 1.24eV to 1.46eV were measured with an electrode gap of 5 cm at 25 ºC. A direct correlation between the standard oxidation potential of the metal and intensity of the behavioral response from the shark has been found. From an application perspective, published standard oxidation potentials greater than 2.00eV are recommended for the greatest repellent effect.

Based on recent studies conducted by NOAA and NMFS, the usage of electropositive metals as selective shark repellents in commercial fisheries holds promise for reducing shark bycatch. Potentiometric measurements have been conducted using a shark fin clipping as the working electrode, a silver ion reference electrode, and seawater electrolyte under temperature, pH, and salinity-controlled conditions. These measurements indicate that shark skin is more electronegative than lanthanide metals and their alloys such as mischmetal.

A mechanism for the electrochemical process of these metals is proposed: A galvanic cell is created by an electropositive metal in seawater, producing trivalent cations which are attracted to electronegative shark skin, leaving a net positive charge on the shark skin electrode. Because of the limited detection range of the ampullae of Lorenzini, it is desirable to place these metals as close to the hook as possible without interfering with capture. A new design is proposed which uses thin ribbons of electropositive metal wrapped around a steel circle hook, ensuring that the structural integrity of the circle hook is maintained during fishing.

- ***Oxidation:***

  $$Ln(s) \Rightarrow Ln^{+3}(aq) + 3e^-$$

- ***Reduction:***

  $$3H_2O(l) + 3e^- \Rightarrow 3/2H_2(g) + 3OH^-(aq)$$

- ***Overall:***

  $$Ln(s) + 3H_2O \Rightarrow Ln(OH)_3\downarrow + 3/2H_2(g)\uparrow$$

Figure 1.—The overall electrochemical reaction, Ln = A Group III metal.

- ***Oxidation:***

  E^o_{298} = 2.25ev to 2.41eV

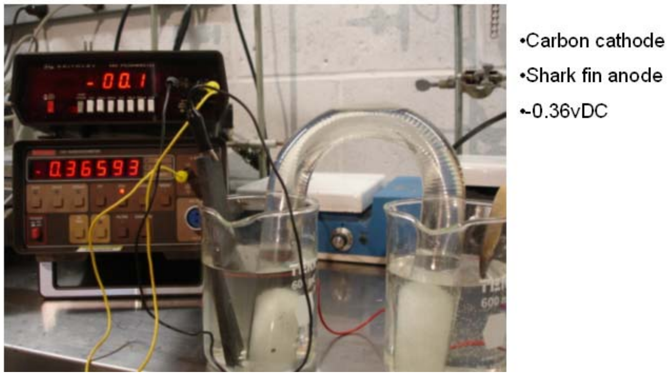
- ***Reduction:***

  E^o_{298} = -0.83eV

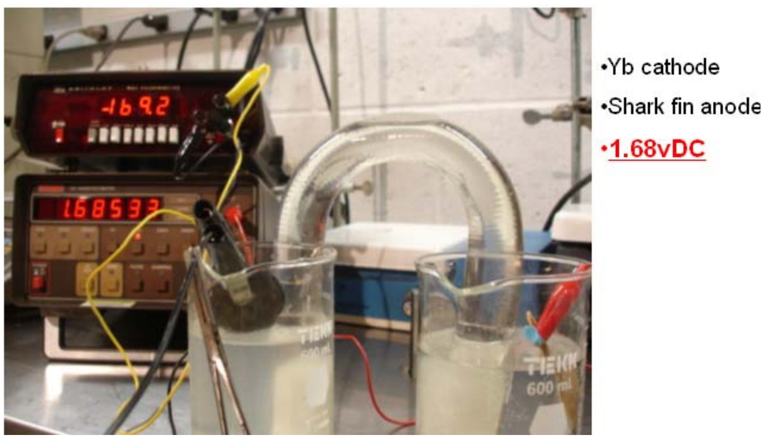
- ***Overall:***

  E^o_{298} = **1.42eV** to **1.52eV**

Figure 2.—The half-cell voltages.



Control: Carbon cathode, - 0.36eV Synthetic seawater electrolyte, 25°C, pH = 8.2



Test: Ytterbium cathode, 1.68eV Synthetic seawater electrolyte, 25°C, pH = 8.2

Figure 3.—A salt bridge apparatus with shark fin clipping used as the cathode.

Chemical Shark Repellents: Identifying the Actives and Controlling Their Release

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Recent advances in chemical shark repellents have produced environmentally compliant compounds which are potent and highly specific to sharks, making them useful for bycatch reduction in commercial fisheries.

Chemical shark repellents developed by Shark Defense Technologies, LLC (www.sharkdefense.com) are based on naturally occurring chemical messengers (semiochemicals) derived from decayed shark tissue. These messengers produce flight reactions in the carcharhinid sharks tested to date, with the shark behavior resembling a *schreckreaktion* (Von Frisch) or fright reaction. The chemical messengers are isolated at specific points during catabolism using solvent extraction and chromatography. These semiochemicals do not produce flight reactions in nearby teleosts (bony fish) and are thus specific to sharks. Tonic immobility studies with precisely controlled dosages and a preliminary electro-olfactogram test also support that the repellent mechanism is via olfaction. Functional requirements and a testing cycle for screening a repellent candidate are provided in Figure 1.

The structures and functions of certain semiochemicals have been elucidated and made more potent using chemical synthesis. In modifying the carbonyl function of one of these molecules, the reactivity appears to shift towards gustation, thus, the repellency occurs when the material is introduced into the mouth of the shark. This compound also appears to be a bony fish attractant. Fish captured to date using this compound are illustrated in Figure 2. Additional modification has yielded highly soluble ketoacid function compounds, which represent a new class of potent repellents that appear to act via olfaction. Responses in tonic immobility tests have been observed at dosages as low as $50 \cdot 10^{-6}$ liters, and a preliminary electro-olfactogram test also produced a large response using a dilute 10^{-4} molar solution.

Shark Defense Technologies has developed two time-release matrices for slowing the delivery using either high-viscosity gels or PEG-ylated actives. With these matrices, chemical repellents are able to protect baits for up to 4 hours in demersal fisheries. Up to 70 mL of gel is readily incorporated into squid baits as shown in Figure 3. An aerosol canister delivery system is now offered for sale, providing a short-term, surface-protecting shark repellent as shown in Figure 4.

Finally, in an effort to maintain green chemistry, Shark Defense Technologies, LLC has performed a detailed compliance assessment of the compounds isolated and synthesized. Regulations from the United States Environmental Protection Agency, Food and Drug Administration, Department of Transportation, and the NMFS were analyzed (refer to Venn diagram in Fig. 5). To date, all repellent candidates are not cited or are compliant with the regulations.

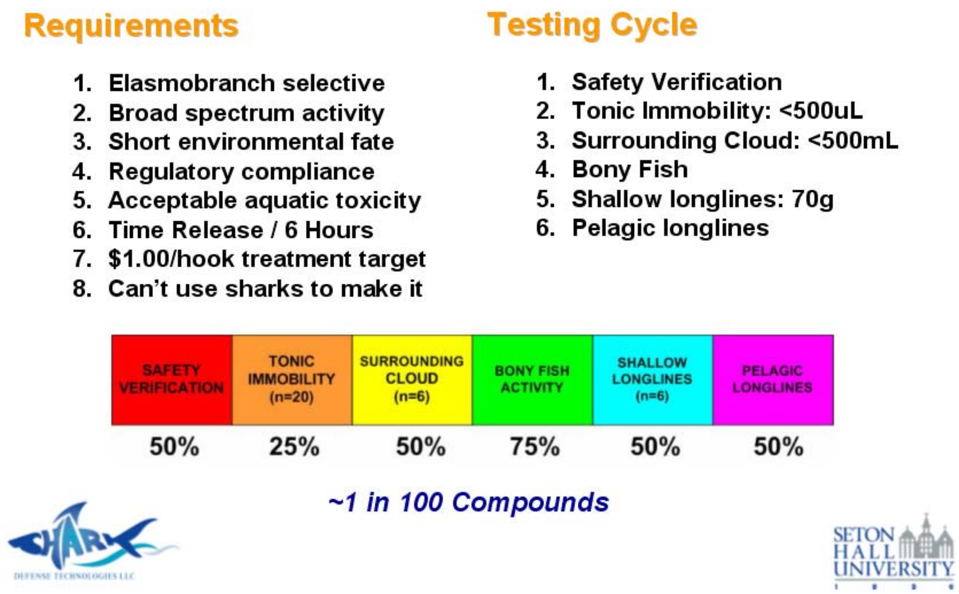

Figure 1.—Repellent requirements and testing cycle.

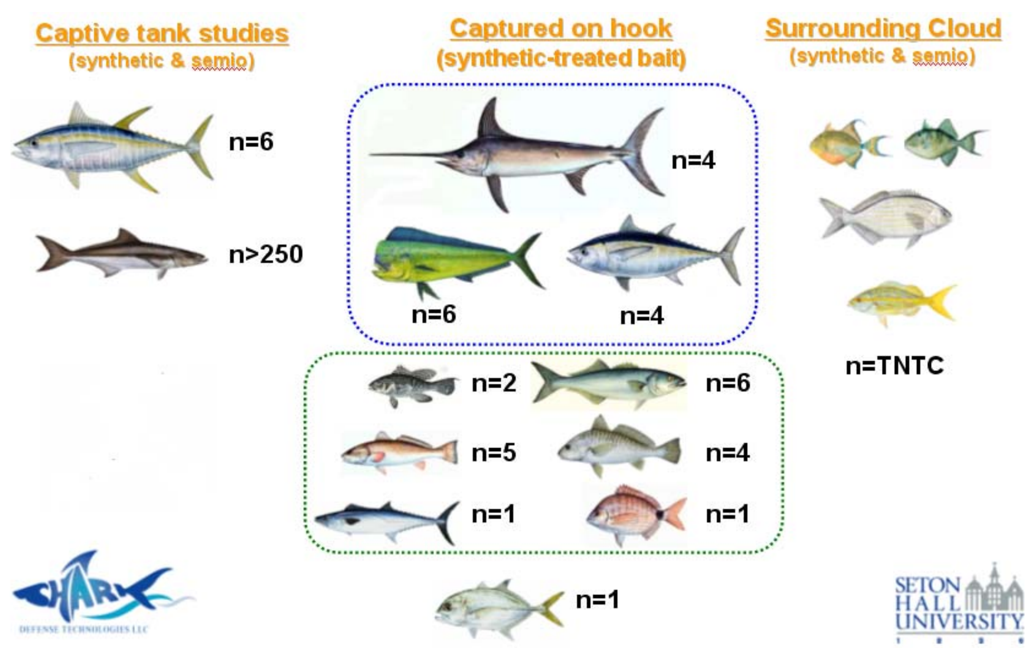

Figure 2.—Bony fish not affected by semiochemical and synthetic shark repellents.

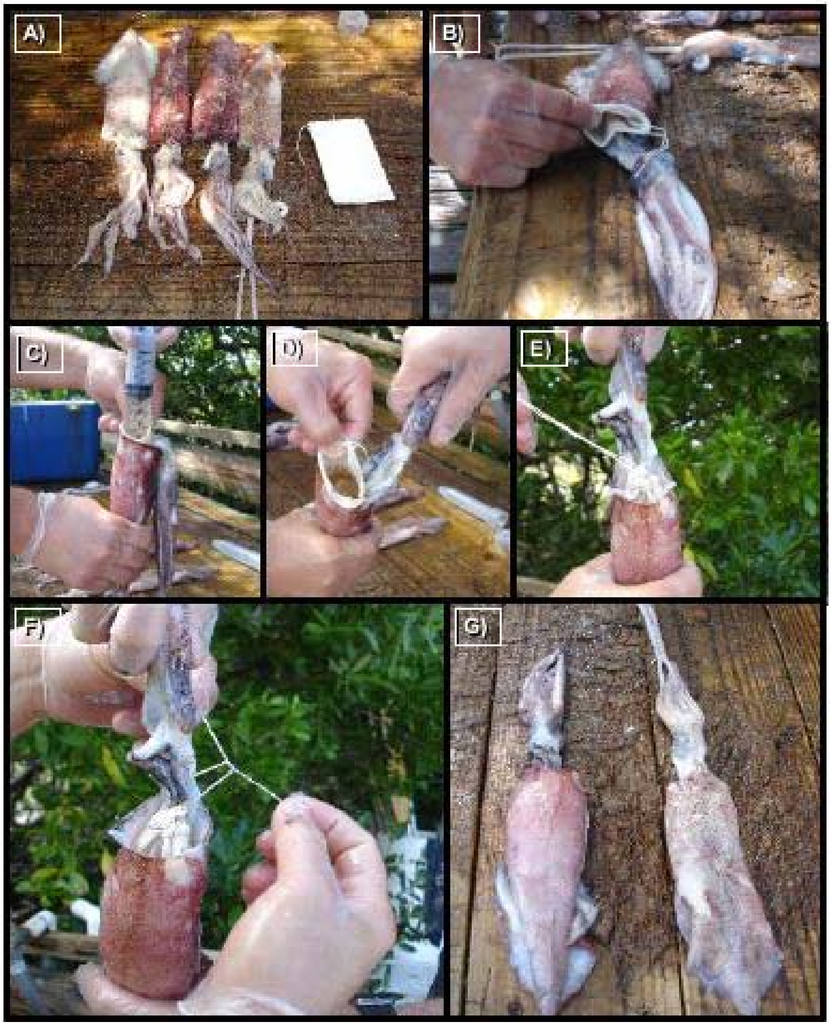

Figure 3.—Method of incorporating gel repellents into squid bait. A) Repellent gel may be directly injected into bait or held in place using a biodegradable muslin bag. B) If a muslin bag is used, it is tucked into the mantle. C) Repellent is inserted using a 60cc syringe. D) View of 70cc of repellent gel held in place with a porous muslin bag. E–F) Muslin bag strings can be tied off around squid body. G) A repellent-treated squid (left) compared to an untreated squid (right).

Figure 4.—Aerosol shark repellent canisters. Left to right: Water-actuated repellent grenade, manually actuated repellent grenade, a 4-can kit useful for fish tagging and trawls.

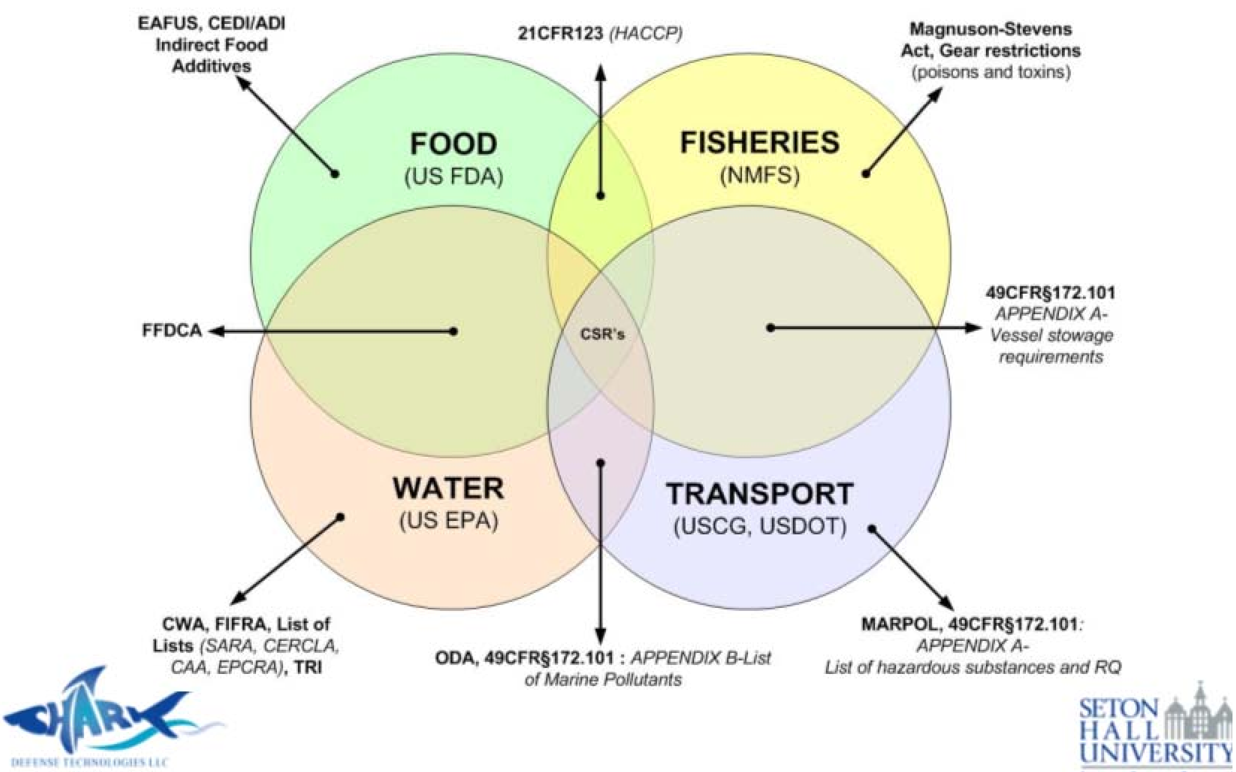

Figure 5.—Venn diagram for compliance assessment of chemical shark repellents.

Investigation of Grade C8 Barium Ferrite ($BaFe_2O_4$) Permanent Magnets as a Possible Elasmobranch Bycatch Reduction System

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Elasmobranchs (sharks, skates, and rays) have a unique electrosensory adaptation enabling the detection of minute electric fields (Kalmijn, 1971, 1982; Kajiura and Holland, 2002). In seawater, Grade C8 Barium-Ferrite ($BaFe_2O_4$) permanent magnets work through electromagnetic induction, creating an electric field that is orders of magnitude greater than that produced by a shark's prey. Various studies conducted on Orectolobiformes, Rajiformes, and Carchariniformes have demonstrated that permanent magnets can manipulate the swimming and feeding behaviors of various elasmobranchs within these orders. Recent hook-and-line studies have demonstrated that the smoothhound dogfish (*Mustelis canis*) is repelled from baited hooks, suggesting that the use of permanent magnets can potentially be used on longlines as a means of selectively repelling elasmobranchs from baited hooks. Also, the data may elucidate behavioral responses of sharks to magnets, which could be used to design a selective shark exclusion barrier on human-populated beaches.

<u>Types of Magnetoreception</u>

- Magnetite based magnetoreception
- Chemical magnetoreception
- Indirect magnetoreception via electromagnetic induction

Figure 1.—Magnetoreception—Several species of elasmobranchs demonstrated ability to detect magnetic fields (Kalmijn, 1971, 1982; Klimley, 1993; Klimley et al., 2002).

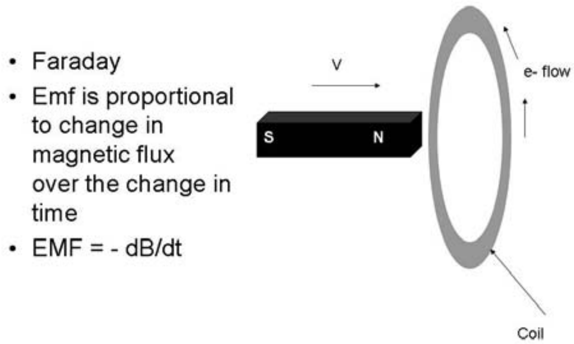


Figure 2.—This figure represents the law of electromagnetic induction.

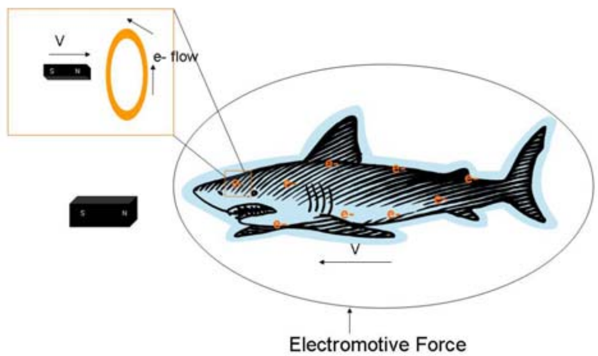


Figure 3.—This figure is a simplified explanation of how electromagnetic induction is related to the ability of elasmobranchs to detect magnetic fields. As an elasmobranch swims towards a permanent magnet, the magnet exerts a force causing all the unpaired electrons throughout the body of the organism to spin in a similar direction. Using the ampullae of Lorenzini, these elasmobranchs can detect the induced voltage created by the movement of these electrons.

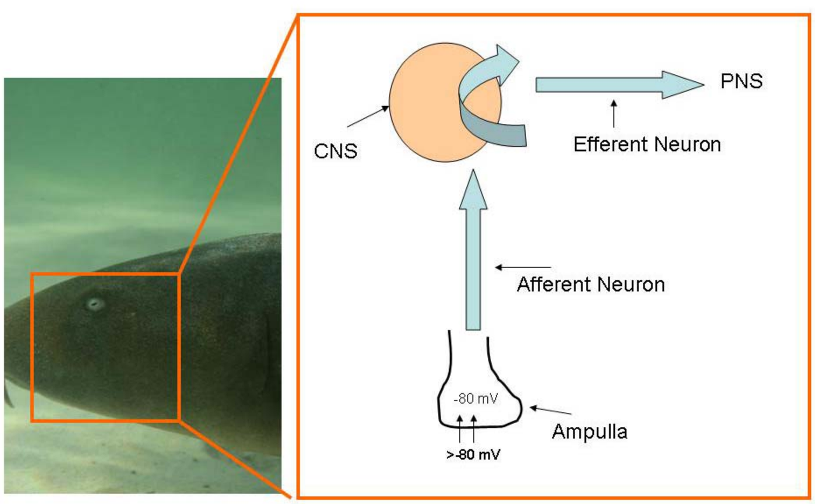
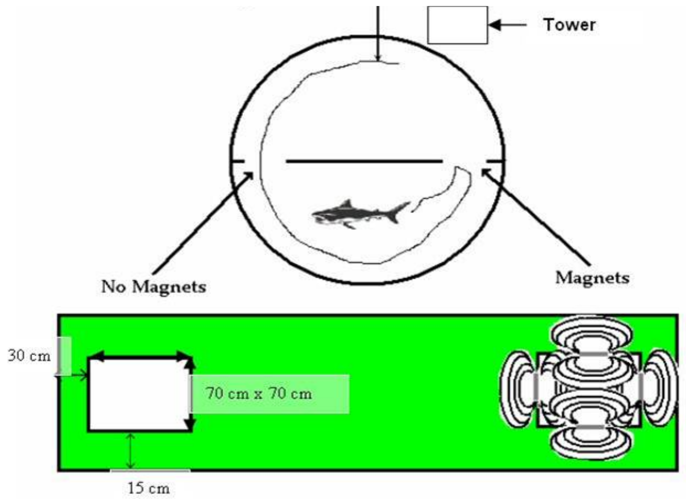


Figure 4.—This figure is a representation of the physiological mechanism behind the ampullae of Lorenzini. This system works primarily on voltage gradients and once a gradient is perceived, an impulse is transmitted to the central nervous system and terminates in the peripheral nervous system where the reaction to the magnetic field occurs (Sherwood et al., 2005).

Hypothetical Shark Swimming Pattern



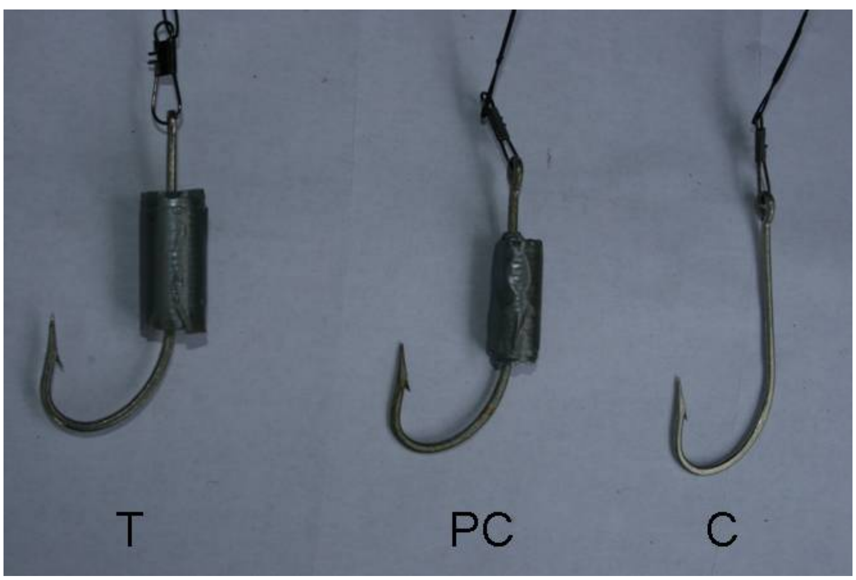
Location: Bimini, BA

Species: Lemon shark
(*Negaprion brevirostris*)

Apparatus: Control vs. Magnets

Behaviors: Entrance through hole
Avoidance Behavior

Figure 5.—Magnetic Fence Experiment. The results observed: 1) Approaches to control (34) versus magnet (40); 2) Entrances to control (10) versus magnet (1); and 3) Avoidances to control (0) versus magnet (22); ($p < 0.01$).



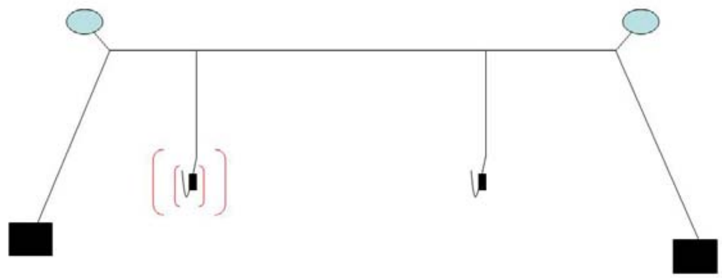
Location: Myrtle Beach, SC

Species: Smoothound Dogfish
(*Mustelus canis*)
Spiny Dogfish
(*Squalus acanthias*)
Clearnose Skate
(*Raja eglanteria*)

Lines: Control (C)
Procedural Control (PC)
Magnetic Treatment (T)

Behaviors: Capture

Figure 6.—Springmaid Study. The results observed per species, where $n = 36$ hours of fishing time: 1) *S. acanthias*—Control (5), Procedural Control (9), and Magnet (2); 2) *S. eglanteria*—C (6), PC (8), and T (3); 3) *M. canis*—C (10), PC (8), and T (1). Combined together, we get—C (21), PC (25), and T (6); ($p < 0.01$).



Location: North Inlet, SC

Species: Atlantic Sharpnose (*Rhizoprionodon terraenovae*)
Blacktip Shark (*Carcharhinus limbatus*)
Bonnethead Shark (*Sphyrna tiburo*)

Apparatus: 2 × 150 m lines:
C-M Line

Figure 7.—This diagram is a simplified version of the design that will be used in a future longline experiment. Each line will be 150 m long and will contain 26 hooks. Throughout the line, the hooks will alternate between a control hook and a magnetic hook.

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Behavioral Responses to Rare Earth Metals During Feeding Events in Two Taxonomically Distinct Dogfish Species: The Effects of Hunger and Animal Density

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The practice of "protecting" baited hooks with electropositive rare earth materials has received extensive attention as a possible means to mitigate shark bycatch in recreational and longline fishing operations. The purpose of this lab-based study was to assess the behavioral responses to these metals in a squaloid, the spiny dogfish (*Squalus acanthias*), and a triakid, the smooth dogfish (*Mustelus canis*), two species commonly captured as bycatch during recreational and commercial hook fishing operations in the western North Atlantic. In distinct species-specific trials, animals were presented with simulated squid-baited fishing lines. For each trial, an electropositive metal ingot (either lanthanide/cerium alloys [mischmetal] or rare earth magnets [neodymium-iron-boride]) and a corresponding minimally reactive stainless steel decoy (control) were deployed as deterrents just above associated baits. In total, 88 videotaped trials were conducted, each persisting until both baits were removed by animals or 20 minutes had elapsed. Behavior (e.g., overt flinch, general avoidance, disregard, bite) of animals around the baits/metals was recorded. Degree of hunger (0 [1 hour], 2 or 4 days without food) and animal density/tank (3 vs.15 conspecifics/tank) were varied to examine the potential influences on bait selectivity in both species while in the presence of the deterrents.

Results show that although the decoy-protected baits were typically attacked first by both species across trials with both metal types, the baits protected by treatment metals were attacked immediately thereafter. Moreover, selectivity of protected baits was inversely related to degree of food deprivation, where both species were virtually unaffected by the repellents after being deprived of food for 2–4 days. Although there were significant differences in bite prevalence (# bites/# overall approaches) as a function of food deprivation in each species, there was no distinction between bite prevalence of control and treatment metal protected baits. Thus, the degree of food deprivation, and not the presence of deterrents, was the primary variable governing feeding behavior in both species of dogfish. Animal tank density, and thus social facilitation, did not have a significant influence on selectivity of baits or feeding behavior in either dogfish species. Results suggest a lack of promise in the ability of these metals to repel the two dogfish species examined and indicate the need to conduct species-specific trials before generalizing the ability of rare earth metals/magnets to reduce the rates of shark interactions in hook fisheries.

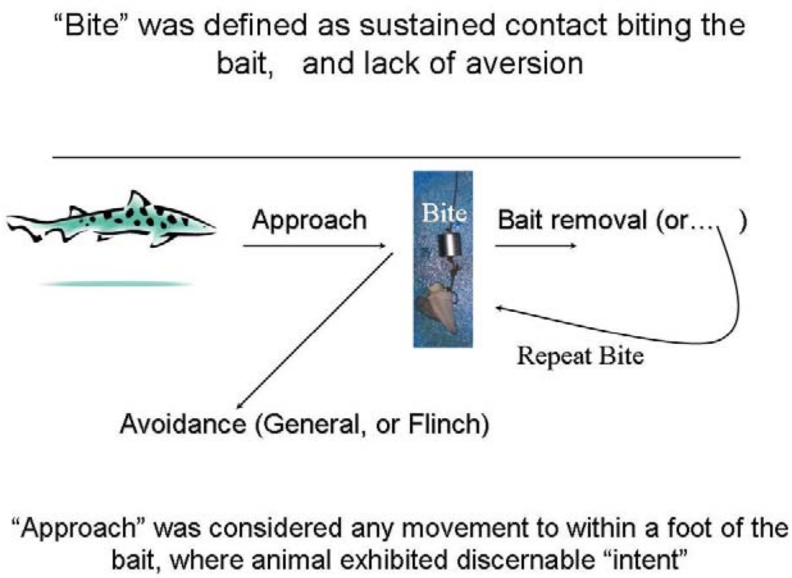

Figure 1.—Experimental coding diagram. Approaches resulted in either a bite (with or without bait removal), or an avoidance (with or without a sharp flinch).

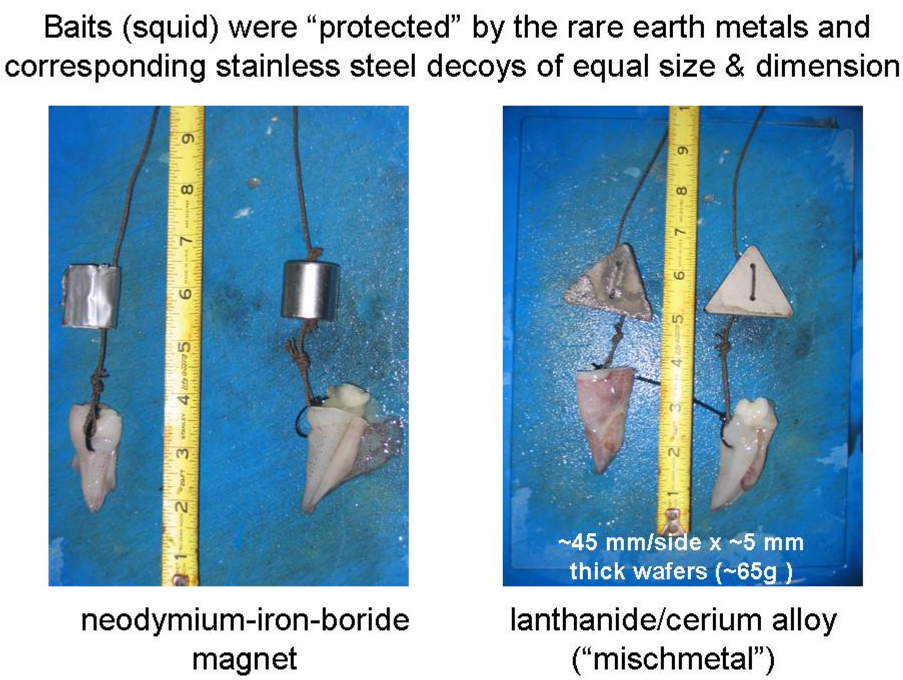

Figure 2.—Experimental setup. Respective metal types and corresponding decoys (controls) were deployed in discrete trials.

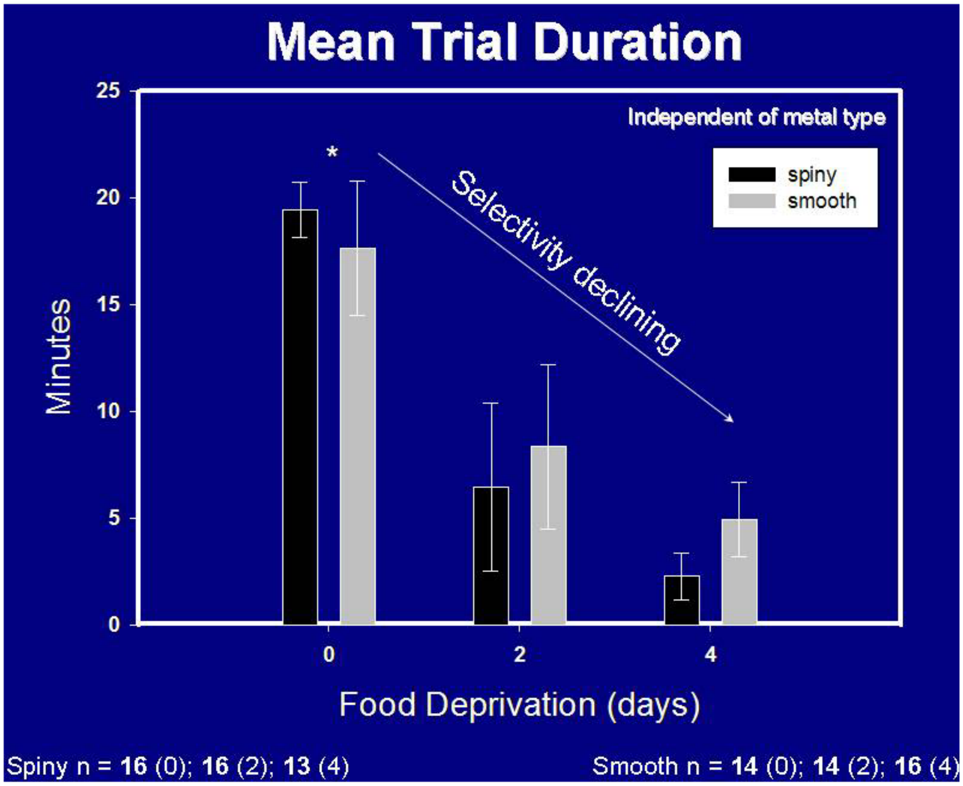

Figure 3.—Trial duration as a function of food deprivation. Selectivity of baits, bite prevalence (on treatment metals and decoys) increased and thus duration of trials declined the longer animals were deprived of sustenance.

CONCLUSIONS

- The feeding behavior of neither dogfish was markedly affected by deterrents (only Time 0 had a minor effect).
- There were no statistically significant differences supporting species-specific responses to respective metal deterrents.
- Degree of hunger was the primary factor influencing bait selectivity in both species.
- Results of this stand-alone lab study raise doubts that either metal could adequately repel these species in a non-controlled field environment.

Can Rare Earth Metals Reduce the Catch of Spiny Dogfish? Applications in Commercial Hook Gears in the Gulf of Maine

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Spiny dogfish (*Squalus acanthias*) are considered to be unacceptably abundant by many inshore fishermen (commercial and recreational) during the summer and fall in the Gulf of Maine. Finding a practical and economic dogfish deterrent for application in various fishing gears is of strong interest. An industry-science collaboration afforded six research trips during September 2007. Triangular slices of a cerium/lanthanide alloy (mischmetal) were incorporated into baited hook gears (longlines and rod and reel gear), and the catches were compared for ‘treatment’ (mischmetal present) versus ‘control’ (mischmetal absent). Some reduction in dogfish catch was recorded for rod and reel (~ 2%) and longline (~ 9–25%), but these results were not statistically significant. One complicating factor was the high rate of mischmetal dissolution, which led to the rapid disintegration of the mischmetal slices. In situ video footage verified that dogfish feeding behavior is persistent on bait regardless of mischmetal presence. This footage also showed that bait pursued by one dogfish would escalate to frenzied feeding by multiple dogfish, with or without mischmetal. Overall, there is little evidence to suggest that mischmetal has the potential to reduce dogfish catches in either commercial or recreational gear types in the Gulf of Maine.

net
“A ~~door~~ is what a dogfish is permanently on the wrong side of” – Ogden Nash

Figure 1.—Dogfish caught in nets in the Gulf of Maine.

Figure 2.—Bycatch reduction: Can rare earth metals reduce the catch of spiny dogfish in commercial hook gears?

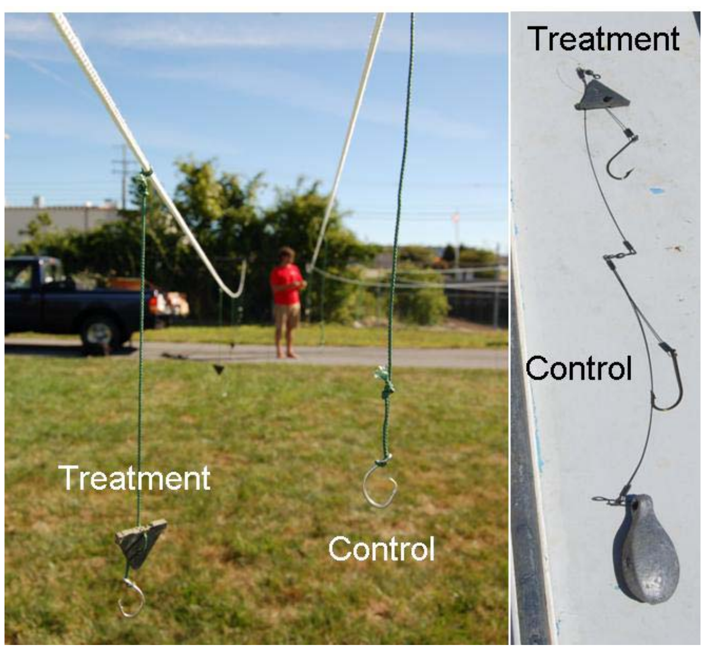


Figure 3.—Control vs. treatment in longline and jig gear.

Table 1.—Dominance of dogfish in the catch.

Trip #	Haddock C	Haddock T	Sea raven C	Sea raven T	Dogfish C	Dogfish T	Dogfish U	Dogfish Total	Dogfish CPUE (100 hks)
1			1		19	17	-	**36**	9.0
2	1			1	6	2	-	**8**	2.0
3	1				59	59	-	**118**	39.3
4					1	0	-	**1**	0.3
5	2				69	62	-	**131**	38.5
6			1		36	36	52	**171**	57.0
Totals	**4**	**0**	**2**	**1**	**237**	**176**	**52**	**465**	**22.4**

C=control, T=treatment, U=Unknown

Table 2.—Summary of dogfish catch (longline and jig).

Trip #	Longline C	Longline T	Longline U	Longline Total	Longline No. hooks	Jig (n=4) C	Jig (n=4) T	Jig (n=4) Total
1	19	17	-	36	400	-	-	0
2	6	2	-	8	400	1	-	1
3	59	59	-	118	300	1	2	3
4	1	0	-	1	340	-	-	0
5	69	62	-	131	340	1	5	6
6	36	36	52	124	340	13	7	20
Totals	**190**	**176**	**52**	**418**	**2,120**	**16**	**14**	**30**

C=control, T=treatment, U=Unknown

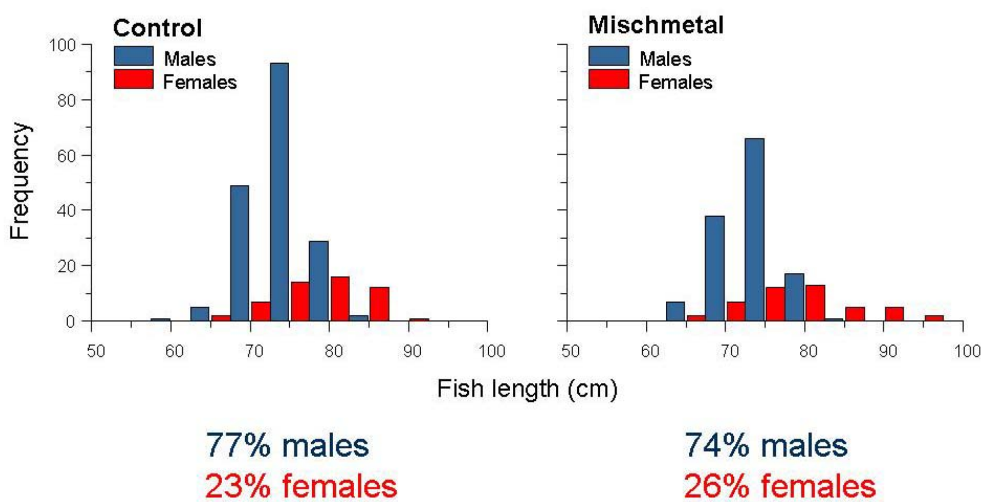


Figure 4.—Description of catch: longlines.

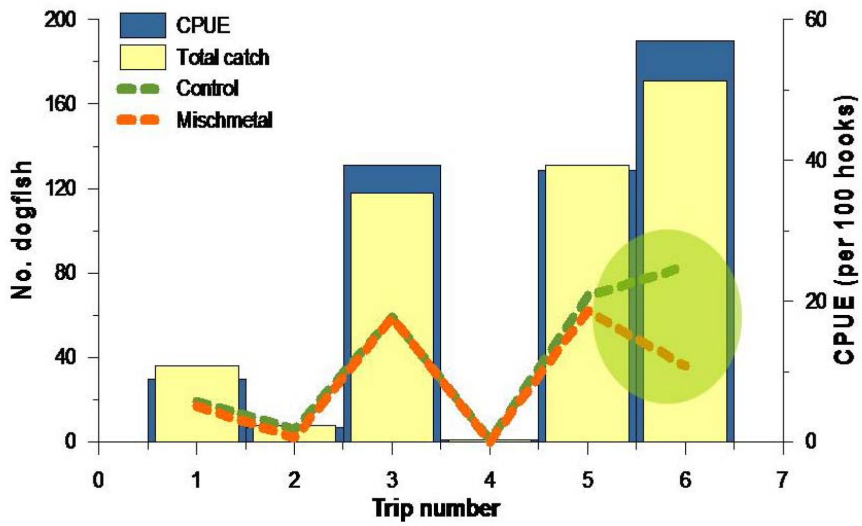
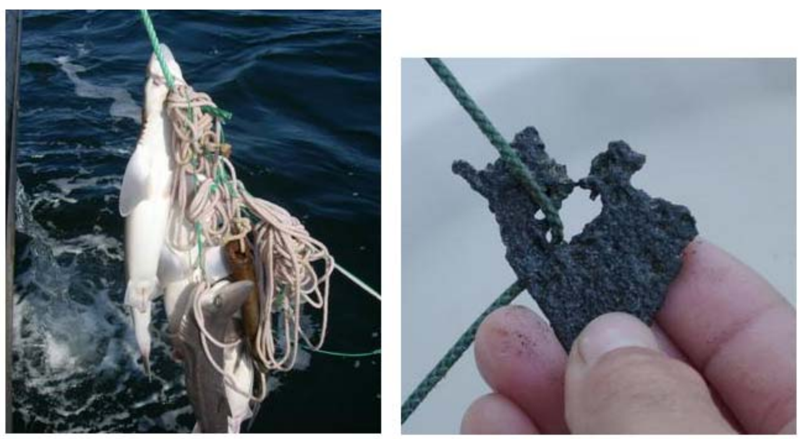


Figure 5.—Catch rates by trip: longlines (2080 hooks set in total).



Line #	No alloy	Alloy of some sort	Unknown	Total dogs
1	22	4	28	**54**
2	31	12	13	**56**
3	30	20	11	**61**
Total	**83**	**36**	**52**	**171**

Figure 6.—Trip 6: Snarls and dissolution caused confusion in data.

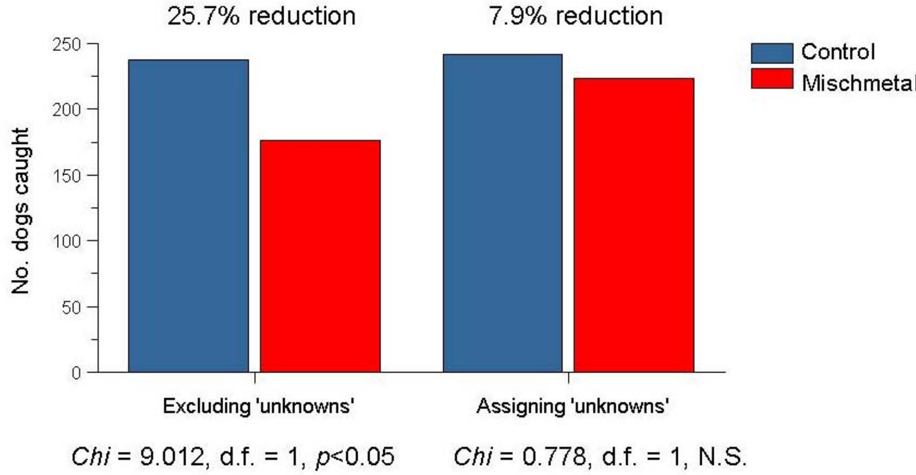


Figure 7.—Reduction in catch of dogfish with mischmetal.

Even if bycatch is dramatically reduced, is it feasible to use mischmetals in commercial fisheries? Mischmetal is costly; it is imported from China via Canada (20% of the cost) and then needs to be cut into slices (80% of the cost). Few metal workshops are familiar with this alloy and are not all willing to cut it once they realize how flammable it is—extreme caution during cutting is needed! Even if all these costs can be reduced, there is still a major problem with dissolution; the mischmetal must be replaced often, and there is also a concern for what effect the mischmetal detritus has on the marine system in which it is being discarded.

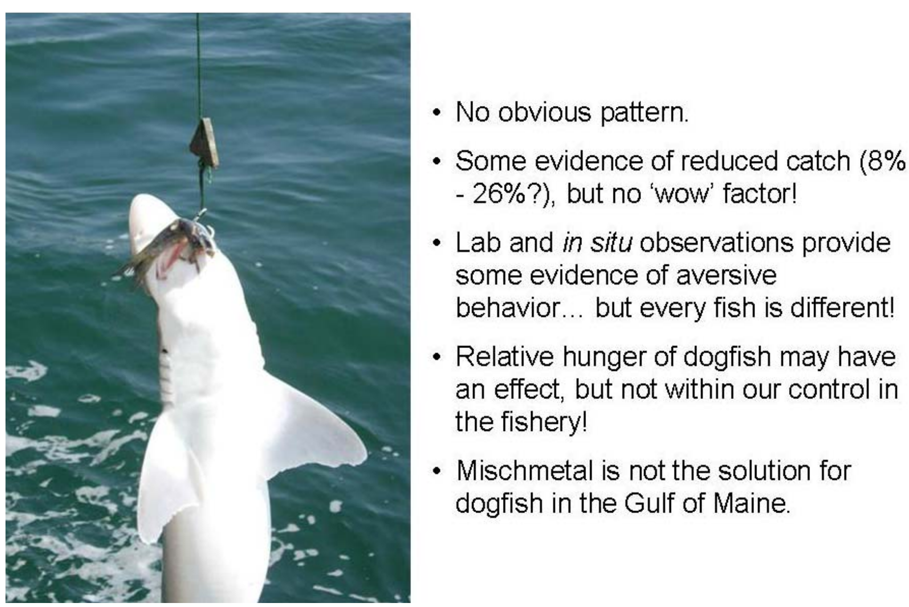


Figure 8.—Can rare earth metals reduce the catch of spiny dogfish in commercial hook gears?

Catch
“~~Scratch~~ a dog and you'll find a permanent job”- Franklin P. Jones

Observing the Behavior of Spiny Dogfish Near Baits Protected with Rare Earth Materials

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Spiny dogfish (*Squalus acanthius*) responded strongly to cerium mischmetal, both in tonic immobility and in laboratory experiments with baits. In pairwise comparisons with unprotected baits, baits protected with mischmetal significantly reduced the number of baits attacked and increased the time to attack and the number of approaches before a first attack. Neodymium-iron-boride magnets produced only a weak response in spiny dogfish and provided no protection for baits. Effectiveness of mischmetal as a deterrent decreased with increasing hunger level and social facilitation. Direct observations on the behavior of sharks in the presence of deterrents will enhance our understanding of deterrent mechanisms.

Bait presentation

Spiny dogfish
41-53, 56-73 cm TL

Video record (20 min)

* Time to strike	* Time to remove	* No. approaches
* No. removed	* First bait removed	* Interactions

Figure 1.—Pools used for testing spiny dogfish predation on baits protected with rare earth metals and magnets. The baits were presented in pairs: cerium mischmetal paired with an aluminum mimic, and a magnet paired with a stainless steel mimic (above right). The baits were presented without hooks. The experiments were monitored with overhead video and analyzed for the variables listed for each of the paired baits.

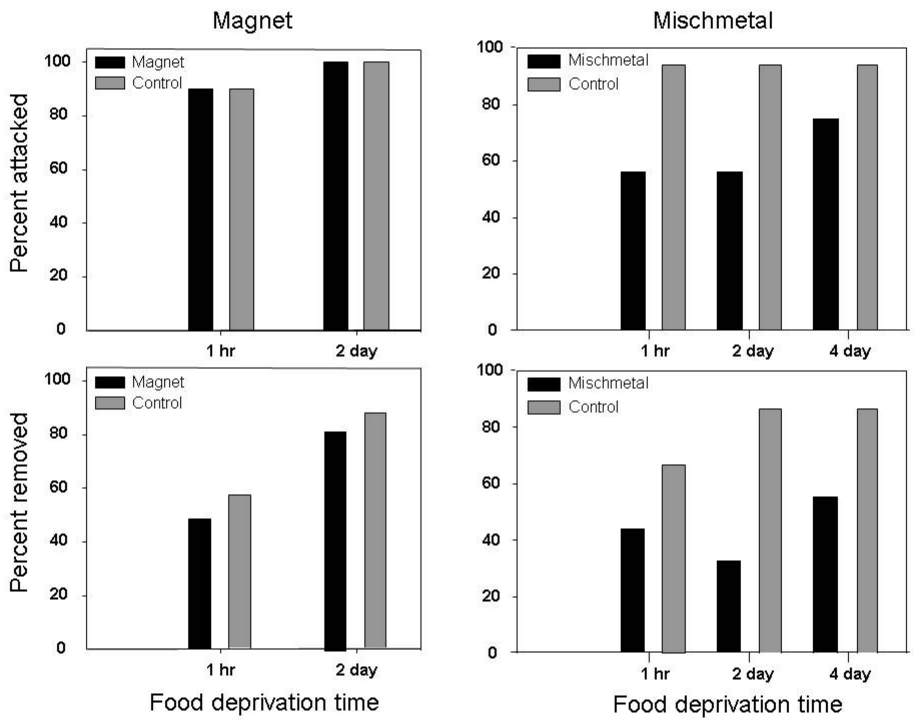

Figure 2.—Percentages of baits attacked and removed by spiny dogfish in experiments testing the deterrent qualities of rare earth magnets (left) and cerium mischmetal (right). Controls made up of nonreactive metals were paired with the rare earth test materials. Trials were conducted at different food deprivation periods to test the effects of hunger. Magnets had no significant effect on bait attack or consumption, while cerium mischmetal had a significant effect at all deprivation levels.

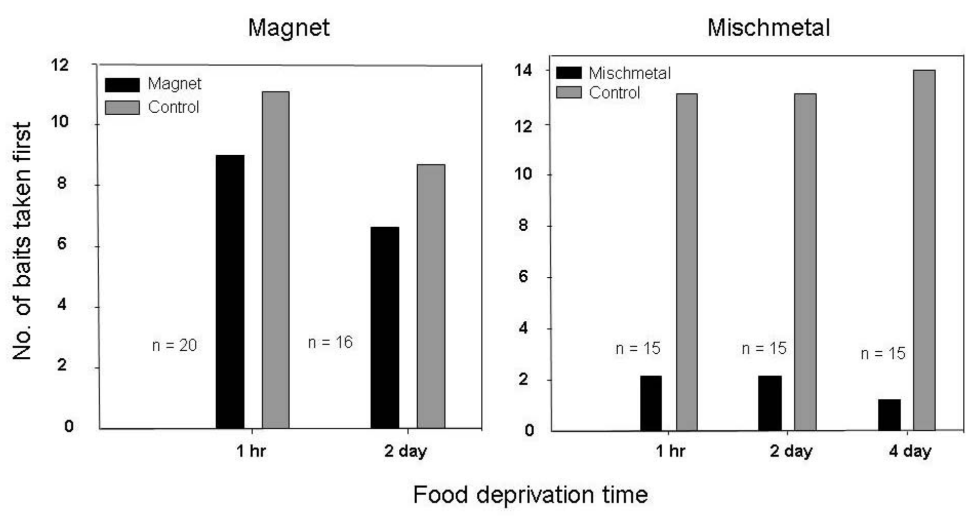

Figure 3.—Numbers of baits removed first by spiny dogfish in pairwise tests of baits protected with rare earth magnets (left) and cerium mischmetal (right). Controls comprised of nonreactive metals were paired with the rare earth test materials. Cerium mischmetal had a major effect at all deprivation levels, while magnets had no appreciable effect.

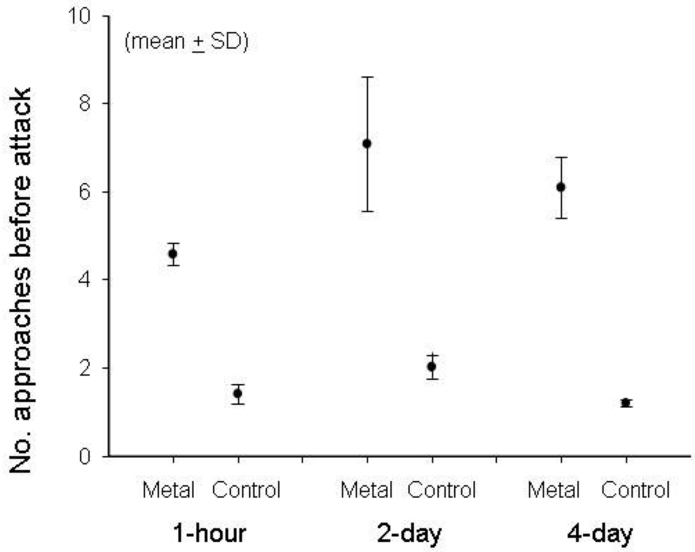

Figure 4.—Numbers of approaches before attack by spiny dogfish to baits protected with cerium mischmetal and control metals. Attacks on mischmetal-protected baits ordinarily occurred with social facilitation (i.e., when multiple dogfish were circling the bait). While control baits were attacked on first encounter in most cases, many approaches were needed before mischmetal-protected baits were attacked.

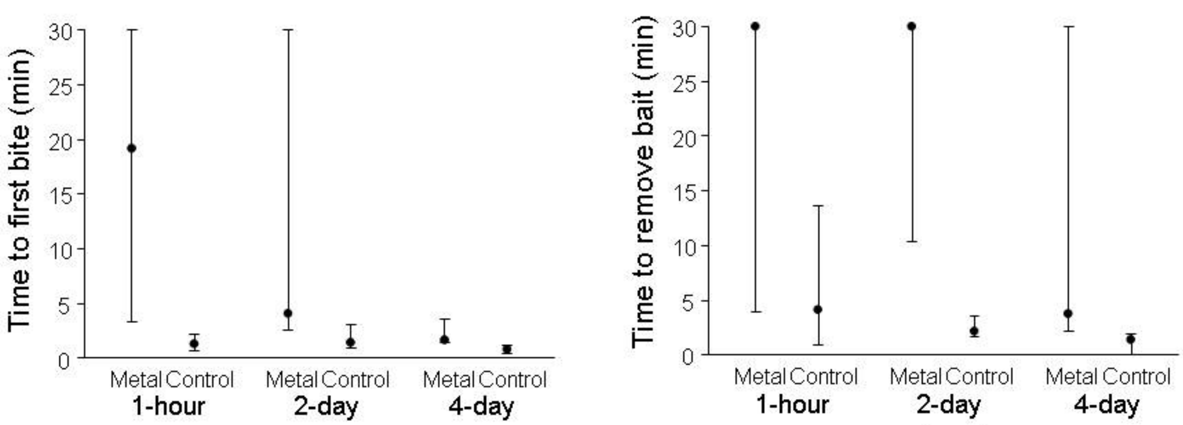

Figure 5.—Times to attack (top) and consume (bottom) baits were significantly higher with cerium mischmetal-protected baits than with control baits at all food deprivation levels. Values are medians with 1st and 3rd quartiles.

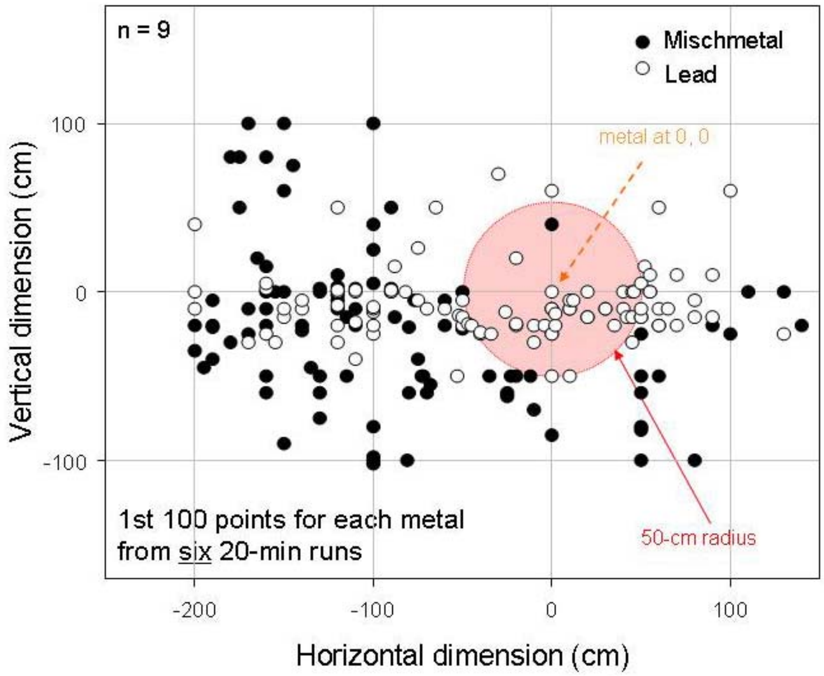

Figure 6.—Positions at which seven-gill sharks passed through the vertical plane surrounding an object suspended in the shark tank at Oregon Coast Aquarium (Newport, Oregon), at the 0, 0 point in the graph. A cerium mischmetal ingot was ordinarily passed at a distance of 50 cm or more (with one exception), while a lead ingot of similar dimension was passed with no apparent deterrence.

CONCLUSIONS

The feeding behavior of spiny dogfish can be modified with cerium mischmetal with possible application in reducing unwanted bycatch on demersal longlines. However, because protection afforded to baits was reduced both by hunger level and social facilitation, it will be critical to conduct field experiments or fishing trials with the rare earth metal. Also, mischmetal is expensive, dissolves quickly in seawater, and is hazardous in cutting, drilling, and transporting—important considerations in shark bycatch reduction.

Preliminary studies with seven-gill sharks ((*Notorynchus cepidianus*), leopard sharks (*Triakis semifasciata*), and bat rays (*Myliobatis californica*) in a large public aquarium show that other elasmobranchs may be more sensitive to rare earth metals than spiny dogfish. Given these results, rare earth metals warrant further attention with regard to bycatch of other problem species.

Reducing Elasmobranch Bycatch: Field Investigation of Rare Earth Metal as a Deterrent to Spiny Dogfish in the Pacific Halibut Fishery

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Spiny dogfish (*Squalus acanthias*) comprise a significant amount of unwanted bycatch on demersal longlines set for halibut and cod in shelf waters off the east and west coasts of North America. Recently, rare earth magnets and metals have been shown to have deterrent effects on sharks. These effects are the result of magnetic or electric fields created by these materials in seawater, which are sensed and avoided by sharks. Our earlier laboratory studies showed that attack rates by spiny dogfish on baits protected with cerium mischmetal (a rare earth alloy) were reduced and suggested that this rare earth metal alloy might reduce unwanted bycatch of spiny dogfish in setline fishing for Pacific halibut (*Hippoglossus stenolepis*).

We conducted a field study near Homer, Alaska in October 2007, with three hook treatments interspersed on 36 longline sets. These included standard circle hooks used in the halibut fishery, hooks with small pieces of cerium mischmetal attached above the hook, and hooks with a similar (but inert) mild steel piece above the hook. Significantly fewer dogfish were caught on hooks with mischmetal than on either of the two other treatments. Reductions in catch of longnose skate (*Raja rhina*) also occurred on hooks protected with mischmetal. However, halibut catch did not increase significantly with protected hooks. The disadvantages of using mischmetal in commercial operations are its high expense, hazardous nature, and relatively rapid hydrolysis in seawater.

In conclusion, we saw no evidence of any effect on the halibut catch and no differences in the number of baits remaining after the set. Perhaps an area with lower dogfish and high halibut presence could have demonstrated a higher effect of the mischmetal.

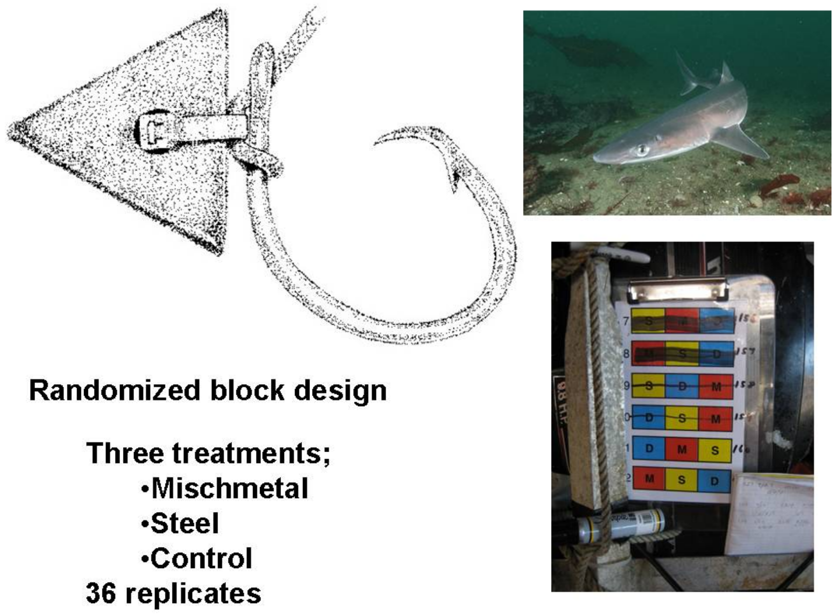
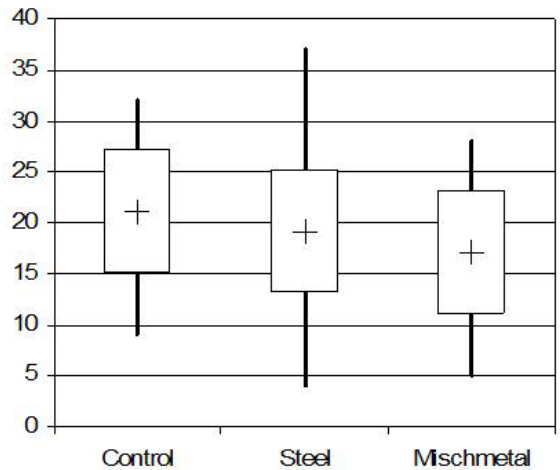


Figure 1.—Circle hook with metal ~ 50 mm on a side 6.3 mm thick triangle attached using an electrical tie. Bottom inset shows setting sheet which gave crew instructions on setting order for each fishing day.

Table 1.—Catch of spiny dogfish, Pacific halibut and other species in experimental longline sets with three different hook treatments. Pacific halibut are summarized by legal (> 82 cm TL) and sublegal sizes for commercial catch.

	Hook Treatment			
Taxa	Standard	Steel	Mischmetal	Total
Spiny dogfish	759	691	612	2062
Halibut >= 82 cm	45	51	45	141
Halibut < 82 cm	80	46	52	178
Longnose skates	24	23	13	60
Sculpins	43	28	42	113
Pacific cod	23	9	10	42
Others	4	4	7	15
Baits remaining	141	160	153	454
Weight (kg)				
Halibut >= 82 cm	400	432	433	1265



	Control	Steel	Mischmetal
Min	9	4	5
Average	21.083	19.194	17.000
Max	32.000	37.000	28.000
StdDev	6.101	7.014	6.761

Figure 2.—Dogfish catch in numbers.

Table 2.—ANOVA and Tukey's multiple comparison tests for dogfish catch on three hook treatments.

	Df	Sum Sq	Mean Sq	F value	Prob (>F)
Set	35	3,739.1	106.8	8.4469	<0.001
Treatment	2	300.7	150.3	11.8873	<0.001
Residuals	70	885.3	12.6		

Contrast	Difference	+/- Limits	Significant difference
Standard vs. steel	1.889	2.007	No
Standard vs. mischmetal	4.083	2.007	Yes
Steel vs. mischmetal	2.194	2.007	Yes

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Terry Bell	Hefa Rare Earth Canada Co. Ltd.
Lee Benaka	NOAA Fisheries, Bycatch Reduction Engineering Program
Richard W. Brill	NOAA Fisheries, Virginia Institute of Marine Science
R. Dean Grubbs	Florida State University
T. Todd Jones	University of British Columbia
Stephen M. Kaimmer	International Pacific Halibut Commission
Stephen M. Kajiura	Florida Atlantic University
John Mandelman	New England Aquarium
Craig O'Connell	Shark Defense, LLC
Patrick Rice	Shark Defense, LLC
Allan W. Stoner	NOAA Fisheries, Alaska Fisheries Science Center
Eric Stroud	Shark Defense, LLC
Yonat Swimmer	NOAA Fisheries, Pacific Islands Fisheries Science Center
Shelly Tallack	Gulf of Main Research Institute
John Wang	University of Hawaii
Tim Werner	The New England Aquarium & The Consortium for Wildlife Bycatch Reduction

BIOGRAPHIES of PARTICIPANTS

Daniel An is the president of Hefa Rare Earth Canada Co., Ltd. Daniel moved to Canada from China and founded Hefa Rare Earth Canada Co., Ltd. in 1998. He has 25 years experience working in the Rare Earth industry, including 8 years as a regional manager for China Non-Ferrous Metals. Daniel holds an engineering degree from Inner Mongolia Agricultural University in Baotou, China.

Terry Bell has been the Sales Manager for Hefa Rare Earth Canada Co., Ltd. since 2005. He has an M.A. degree in International Affairs from the Norman Patterson School at Carleton University with research focusing on Chinese economic integration and multinational corporations. Terry recently completed 5 months of Mandarin language training at the University of International Relations in Beijing.

Lee Benaka is the National Coordinator of the Bycatch Reduction Engineering Program. He has worked for NOAA Fisheries since 1999; first for the Saltonstall-Kennedy Grant Program and currently in the Domestic Fisheries Division of the Office of Sustainable Fisheries. Prior to that, Mr. Benaka worked as a contractor in the Atlantic Highly Migratory Species Division of the Office of Sustainable Fisheries. In addition, Mr. Benaka was the first American Fisheries Society (AFS)/Sea Grant Fellow, and in that capacity he edited Fish Habitat: Essential Fish Habitat and Rehabilitation (AFS 1999).

Richard Brill received his Ph.D. from the John A. Burns School of Medicine in Biomedical Physiology. He was with the Honolulu Laboratory of the National Marine Fisheries Service (now the Pacific Islands Fisheries Science Center) from 1982 until 2002 where he conducted physiological studies on tunas and open ocean tracking studies of tunas, billfishes, and sharks. He is currently Director of the NMFS Cooperative Marine Education and Research Program located at the Virginia Institute of Marine Science. His primary fields of interest are the physiological ecology, sensory biology, and bioenergetics of fishes.

R. Dean Grubbs is a Fish Ecologist with interests in the biology of recreationally and commercially important estuarine and marine fishes, primarily top predators. Much of his research addresses specific biological gaps necessary for management of fisheries resources, especially coastal and deepwater elasmobranchs and large pelagic teleosts. Dr. Grubbs specializes in the use of fishery-independent survey methods to study population dynamics, habitat use, and distribution patterns of fishes. As an extension of this, his research includes the use of conventional mark-recapture methods and modern telemetry techniques to acquire data on movement patterns, habitat use, residency and philopatry. A principal goal of this line of research is to delineate essential and vulnerable habitats for exploited or threatened species. Other areas of expertise include studies of trophic ecology, growth, and reproduction. Dr. Grubbs received his B.S. in Marine Science/Biology from the University of Miami and his Ph.D. in Fisheries Science from the College of William & Mary. He is currently on the research faculty at the Florida State University Coastal and Marine Laboratory.

T. Todd Jones received his M.Sc. in the Department of Biological Sciences at Florida Atlantic University and is completing his doctoral degree in the Department of Zoology at the University of British Columbia. He is interested in the area of bioenergetics and conservation physiology. He has examined the bioenergetics (energy use/allocation) of marine sea turtles and how resource availability, abundance and human perturbations such as climate change affect their reproductive output and growth. His research is based on the fundamental principle that growth rate and metabolic rate are two important factors for understanding and managing a species.

Stephen M. Kaimmer completed his B.Sc. at McGill University in 1972 with an Honours program in Aquatic Ecology. He received a Masters degree from Western Washington University in 1976 with a thesis on enzymatic adaptation to temperature régimes in Walleye Pollock. In between, he worked for the National Marine Fisheries Service in Seattle and as a crewman on a halibut vessel in southeastern Alaska. Steve has worked at the Halibut Commission in Seattle since 1985. His interests have included halibut release injury and mortality and many aspects of hooking behavior. He developed the IPHC pit tagging protocol, and most recently has been using a Didson sonar to develop a directly determined hooking success curve for Pacific halibut.

Stephen M. Kajiura completed his B.Sc. degree in Marine Biology at the University of Guelph, his M.S. degree in Marine Biology at the Florida Institute of Technology with Dr. Tim Tricas and his Ph.D. in Zoology at the University of Hawaii with Dr. Kim Holland. In January 2002, Dr. Kajiura joined the Biomechanics Laboratory of Dr. Adam Summers at the University of California Irvine as a post-doctoral researcher. Dr. Kajiura joined the faculty at Florida Atlantic University in Boca Raton in January 2004. His research continues to focus upon sensory biology of elasmobranch fishes including the visual, olfactory and electrosensory systems.

John Mandelman is a Research Scientist in the Research Department of the New England Aquarium. He received a doctorate in Biology from Northeastern University, where he is currently a part-time faculty member. John's research primarily focuses on the physiology of elasmobranchs (sharks, rays and skates) and has addressed many fisheries-related topics. More specifically, he studies bycatch and post-release survivorship, and the physiological impacts of capture on fishes (especially sharks).

Craig P. O'Connell is a Masters student at Coastal Carolina University where he is studying elasmobranch magnetoreception and hopes his findings contribute to the development of elasmobranch bycatch technology. He is also a research assistant for Shark Defense, LLC and in the future plans to receive his Ph.D. and eventually become a professor.

Patrick Rice just defended his Doctoral thesis from the Marine Biology and Fisheries Division at the Universtiy of Miami - RSMAS and due to graduate this semester (May '08). His research interest includes sensory biology of pelagic animals with applications for reducing bycatch during commercial fishing.

Allan Stoner has been the head of AFSC's Fisheries Behavioral Ecology Program and is a graduate faculty member at Oregon State University since 2000. He and other Program members combine laboratory and field experimentation with direct observations on economically important fishes and crabs (all life stages) to understand principles of essential fish habitat and recruitment process. The group also conducts research aimed at improving survey methods and reducing unwanted bycatch and discard mortality in trawl, longline, and pot fisheries. Al finished his Ph.D. in Florida and then spent 15 years working in Puerto Rico and the Bahamas and 4 years at the Northeast Fisheries Science Center before arriving at AFSC. He has > 500 days at sea on oceanographic and fishing vessels and has published more than 100 peer-reviewed papers.

Eric Stroud is the cofounder of Shark Defense, LLC and has been researching selective shark repellents since 2001. Eric received his B.S. in Chemical Engineering and M.S. in Environmental Engineering from the New Jersey Institute of Technology and is currently a Ph.D. student at Seton Hall University, New Jersey, researching chemical signals.

Yonat Swimmer is a Fisheries Biologist at the NOAA-Fisheries Pacific Islands Fisheries Science Center. Yonat has worked on the nesting ecology of leatherback, loggerheads, green and hawksbill turtles in the Caribbean, Brazil, and Hawaii. Yonat received her M.S. and Ph.D. from the University of Michigan. Her dissertation involved the link between the behavior and physiology of basking green turtles in the Northwestern Hawaiian Islands. Yonat has long been fascinated with the field of physiological ecology. Since 2001, she has spent most of her time investigating means to reduce the interaction of sea turtles with longline fishing gear, as well as understanding the impacts of these interactions on turtles' survivorship and behavior.

Shelly Tallack is an associate research scientist at the Gulf of Maine Research Institute with considerable experience working with fishermen and working on commercial and research vessels in a variety of different countries and ecosystems, including Scotland, Norway, Jamaica, the United States and Australia. Shelly's research has three primary foci: 1) studying the movement and migration of trans-boundary commercial species (e.g., cod and haddock), 2) assessing the survivability of bycatch and discards, and 3) investigating fishing methods to improve gear selectivity and to minimize impacts on nontarget marine organisms.

John H. Wang is an associate researcher with the Joint Institute for Marine and Atmospheric Research at the University of Hawaii-Manoa. His research interests have focused on the sensory systems of marine animals and, in particular, on the sensory cues used during orientation and navigation. He has examined the neurobiological basis of magnetic orientation in the nudibranch, *Tritonia diomedea*. In addition, he has studied how juvenile sea turtles use the Earth's magnetic field to determine their geographic position as well as how hatchling turtles use wave cues during their initial offshore migration. John is currently working with NOAA Fisheries, Pacific Islands Fisheries Science Center, Fish Biology and Bycatch Program to investigate the sensory cues that lead incidentally caught species to interact with fishing gear and to develop strategies that would be useful in reducing bycatch in the fisheries. John received his Ph.D. from the University of North Carolina at Chapel Hill in 2004.

Tim Werner is a senior research scientist at the New England Aquarium and Director of the Consortium for Wildlife Bycatch Reduction, a group of engineers, fishermen, and biologists engaged collaboratively in the research and development of alternative fishing techniques that reduce the bycatch of threatened marine species. Prior to joining the Aquarium in 2005, Tim served as a senior director at the environmental nonprofit organization Conservation International, where he oversaw programs that supported the creation of marine and terrestrial protected areas in Latin America and the South Pacific, and developed "eco-businesses" with rural communities. He has organized and led field expeditions involving wildlife biologists and fisheries scientists to document coral reef biodiversity in Indonesia, Philippines, Papua New Guinea, Solomon Islands, and Brazil. In addition to his focus on bycatch reduction, Tim is part of an international team of scientists studying the biology and management of sea cucumbers. Tim holds graduate degrees in Marine Zoology from the University of Maryland and in Business Management from Stanford University where he was a 2001 Sloan Fellow.

Group Photo

From Left to Right: Tim Werner, Daniel An, Shelly Tallack, John Mandelman, T. Todd Jones, John Wang, Steve Kaimmer, Dean Grubbs, Terry Bell, Yonat Swimmer, Eric Stroud, Richard Brill, Craig O'Connell, NEAq Intern, Stephen Kajiura, Allen Stoner, NEAq Intern, Patrick Rice. Not present in picture is Lee Benaka.

Availability of NOAA Technical Memorandum NMFS

Copies of this and other documents in the NOAA Technical Memorandum NMFS series issued by the Pacific Islands Fisheries Science Center are available online at the PIFSC Web site http://www.pifsc.noaa.gov in PDF format. In addition, this series and a wide range of other NOAA documents are available in various formats from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, U.S.A. [Tel: (703)-605-6000]; URL: http://www.ntis.gov. A fee may be charged.

Recent issues of NOAA Technical Memorandum NMFS–PIFSC are listed below:

NOAA-TM-NMFS-PIFSC-11 Linking Hawaii fisherman reported commercial bottomfish catch data to potential bottomfish habitat and proposed restricted fishing, areas using GIS and spatial analysis.
M. PARKE
(September 2007)

12 2006 Sea turtle and pelagic fish sensory physiology workshop, September 12-13, 2006.
A. SWIMMER and J. H. WANG (comps. and eds.)
(October 2007)

13 Corrected catch histories and logbook accuracy for billfishes (Istiophoridae) in the Hawaii-based longline fishery.
W. WALSH, K. BIGELOW, and R. ITO
(December 2007)

14 Hawaiian Archipelago Marine Ecosystem Research (HAMER).
HAWAII DIVISION OF AQUATIC RESOURCES, PAPAHĀNAUMOKUĀKEA MARINE NATIONAL MONUMENT, NOAA PACIFIC ISLANDS FISHERIES SCIENCE CENTER, UNIVERSITY OF HAWAII, U.S. FISH AND WILDLIFE SERVICE, WESTERN PACIFIC REGIONAL FISHERY MANAGEMENT COUNCIL (compilers)
(February 2008)

15 Rationalizing the formula for minimum stock size threshold (B_{MSST}) in management control rules.
P. KLEIBER
(April 2008)